THE GASEOUS METABOLISM OF INFANTS

WITH SPECIAL REFERENCE TO ITS RELATION TO PULSE-RATE AND MUSCULAR ACTIVITY

BY

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PREFACE.

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These observations were made in the Children's Department of the Massachusetts General Hospital with an apparatus belonging to the Nutrition Laboratory. The experimental technique was exclusively under the charge of Miss Alice Johnson, of the Nutrition Laboratory staff. For her extraordinarily painstaking skill and fidelity we are under great obligations.

Of the numerous co-workers in this research we wish especially to mention Doctors S. Morgulis and J. L. Gamble, and of the various house officers and nurses, Dr. R. E. Eustis, Dr. Clifford B. Sweet, and the Misses Trainer, Sullivan, and Richardson.

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Nutrition Laboratory of the
Carnegie Institution of Washington,
Boston, Massachusetts, February 7, 1914.

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PART I.

INTRODUCTION.

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Observations on the metabolism of infants have for the most part been confined to records of food intake, changes in body-weight, and analyses of urine and feces. Studies of the gross metabolism of the body, necessitating either direct calorimetric observations or measurements of the gaseous exchange, demand elaborate apparatus and unusual technique and hence they have been precluded in most clinics and laboratories. Before entering into a discussion of our researches in this field, it is desirable to cite briefly the evidence on the gaseous exchange of infants thus far published.

The earliest record that we have been able to find of the measurement of the gaseous metabolism of an infant is that reported by J. Forster, of Munich, in 1877.[1] In an effort to explain the well-known fact that children consume a larger amount of food in proportion to their body-weight than do adults, this investigator made determinations of the carbon-dioxide excretion in 14 experiments on children varying in age from 14 days to 9 years. His results all showed that 10 or 12 grams of carbon dioxide were given off per hour for every 10 kilograms of body-weight. With adults on the same basis, the carbon dioxide given off under conditions of rest and approximate hunger was 4 to 5 grams per hour; with an average diet, 5 to 6 grams; and with food and work, 7 grams. The author points out that the youthful organism, even in the condition of hunger, produces per unit of weight at least twice the amount of carbon dioxide which is produced by the adult body. The fact is also recognized that the infant can develop a considerable amount of work, as will be seen by the following quotation:

> "Bedenkt man noch die relativ grossen Arbeitsleistungen, welche die meist lebhaften kindlichen Körper ausführen, so ergibt sich, dass eine relative Mehrzufuhr von Speisen für den kindlichen Organismus eine durch innere Verhältnisse bedingte Nothwendigkeit ist."

The experiments were made with the large Pettenkofer-Voit respiration chamber in Munich, but the protocols were never published, and aside from the statement that the children were at rest, no further details are given as to the muscular activity or the pulse-rate.

In 1885 Richet,[2] in describing his calorimeter, states that he has two chambers, one of which, having a capacity of about 1,500 liters of air, is used for experiments with infants. He cites an experiment with an infant of 9 kilograms, who was in the chamber for 1 hour and 10 minutes,

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[1]Forster, Amtl. Ber. d. 50. Versammlung deutsch. Naturforscher u. Aerzte in Munchen, Munich, 1877, p. 355.

[2]Richet, Archives de Physiol. norm. et path., 1885, **15**, 3d ser., p. 237.

and gives protocols for another experiment, 1 hour in length, presumably with the same infant. In summing up his averages he refers to numerous experiments on infants weighing from 6 to 9 kilograms and includes observations made with environmental temperatures ranging from 18° C. to 25° C. He concludes that the infant produces on the average 4 calories per kilogram of body-weight per hour. Richet discusses especially the relationship between the body-surface and the heat-production.

Two years later, Langlois[1] conducted experiments on children with Richet's calorimeter, in which only the heat-production was measured. From 17 controlled experiments, all with infants weighing about 7 kilograms, Langlois concludes that the heat-production is increased as the environmental temperature is lowered. As a result of a study on the influence of the time of day upon the heat-production, he also concludes that there are two maximum values at approximately 11 a. m. and 3 p. m., corresponding to the values for the absorption of oxygen found by Fredericq.[2]

TABLE 1.—*Relationship between heat-production and body-weight of infants* (Langlois).

Body-weight.		Heat-production per kilogram of body-weight.
	kilos.	*cals.*
Two children at	1.8	6.40
Child of	2.5	4.80
Children from	3.0 to 4.0	4.20
Children from	7.0 to 8.0	4.12
Children from	9.0 to 10.0	3.93

TABLE 2.—*Relationship between heat-production and body-surface of infants* (Langlois).

Body-weight.	Body-surface.	Heat-production.		
		Per kilogram of body-weight.	Per unit of surface.	Per sq.meter of body-surface.[2]
kilos.		*cals.*	*cals.*	*cals.*
10	9.142[1]	3.920	17	1,690
9	2.106	3.900	16	1,620
7	1.778	4.120	16	1,580
6	1.638	4.200	15	1,500
4	1.135	4.300	15	1,370
2	0.780	6.000	15	1,510

[1]This figure is quoted from Langlois and as his discussion of body-surface is very confusing, it is impossible to make a correction which is obviously much needed.
[2]As calculated by Camerer, using Meeh's formula (Camerer, Der Stoffwechsels des Kindes, Tübingen, 1896, p. 109).

Langlois's discussion of the relationships between the heat-production and the body-weight and the heat-production and the body-surface is of special interest in connection with our research. As will be seen

[1]Langlois, Centralbl. f. Physiol., 1887, **1**, p. 237. [2]Fredericq, Arch. de Biol., 1882, **3**, p. 731.

from his figures given in table 1, the smaller the child the larger was the heat-production per kilogram of body-weight. The author points out, however, that if the heat-production and body-surface are compared, as is done in table 2, the uniformity is remarkable. He gives a very unsatisfactory explanation of his unit of surface, but brings out the fundamental idea that the heat per unit of body-surface is essentially the same for an infant as for an adult weighing 65 kilograms, namely, 14 to 17 calories. No information is given regarding the muscular activity, the age, or the pulse-rate of these infants.

In another paper, Langlois[1] refers to Richet's observations on normal children weighing from 7 to 10 kilograms with a heat-production of approximately 4,000 calories per kilogram per hour, and reports his own results with sick infants in which he finds a direct relationship between the body-temperature and heat-production. Infants having temperatures below 37.5° C., which he takes as normal, had a heat-production less than 4 calories per kilogram of body-weight per hour, while those with temperatures above 37.5° C. had a higher heat-production; thus, with a body-temperature of 35.5° C., the heat-production was equal to 2,900 calories, while with a body-temperature of 40.5° C., it was equal to 4,600 calories.

Langlois's calorimeter was subsequently used by Variot and Saint-Albin[2] in studying the calorimetry of atrophic infants. The tests of this calorimeter published by Saint-Albin[3] show a possible error of plus or minus 10 per cent, thus indicating that the apparatus can hardly be considered an instrument of precision. As Saint-Albin himself points out, his check tests differ considerably from those of Langlois.

Variot and Saint-Albin studied a large number of atrophic infants; their conclusions, reported by Saint-Albin, are especially interesting in connection with this report of our researches, as they show that (using their terminology) out of 33 atrophic infants, there were 11 "hyperrayonnants," 16 "hyporayonnants," and 6 "rayonnants normalement."[4]

Of the numerous forms of calorimeters reported to the French scientific societies by d'Arsonval, one[5] was employed by Bonniot[6] in 1898 for a study of the heat-production of infants with temperature disturbances, but he found no regular relationship between heat radiation and rectal temperature. A detailed presentation of Bonniot's results may be found in his thesis for 1900.[7]

[1]Langlois, Compt. rend., 1887, 104, p. 860.

[2]Variot and Saint-Albin, Bull. de la Soc. de Pediatre. 1903, **5**, pp. 246 and 307. See, also, an extensive discussion of these researches in the thesis by Saint-Albin, Etude sur la calorimétrie des infants atrophiques, Paris, 1904, No. 295.

[3]Saint-Albin, loc. cit., p. 25. [4]*Ibid.*, p. 39.

[5]See note on this particular calorimeter by d'Arsonval, Mem. de la Soc. de Biol., 1898, p. 248.

[6]Bonniot, Mem. de la Soc. de Biol., 1898, p. 249. For a critique of the Richet and d'Arsonval calorimeters, see Bonniot, Calorimetrie infantile. Etat de la question. Clinique Infantile, 1906, **4**, p. 289.

[7]Bonniot, De l'hyperthermie dans la fiévre; essai de calorimétrie clinique, Paris, 1900, No. 419.

The most recent contribution from French laboratories on direct calorimetry with which we are familiar is that of Variot and Lavialle[1] in 1912. In this interesting communication, in which the fundamental principles of infant calorimetry are well considered, the authors state that they used the modified form of the d'Arsonval calorimeter which was calibrated by electrical resistance. The gaseous metabolism was not studied and no statement was made as to the muscular activity of the infants. The authors conclude that the heat-output of infants increases in proportion as the weight decreases and lay great emphasis upon the effect of clothing upon radiation. They likewise believe that the supply of adipose tissue may materially modify the radiation.

Mensi[2] of Turin, without stating the apparatus employed or even the fundamental principle, reports a series of observations on 5 new-born infants varying in age from 6 hours and 5 minutes to 7 days, 17 hours, and 54 minutes. In these experiments the oxygen consumption was determined as well as the carbon-dioxide production. The results are given in table 3. The statement is made that the infants were quiet in each case, but no pulse records are given.

TABLE 3.—*Summary of experiments on respiratory exchange of new-born infants* (Mensi).

Age.	Sex.	Body-weight.	Length of experiment.	Oxygen consumed.			Carbon dioxide produced.				Respiratory quotient.
				Total.	Per minute.	Per kilogram per minute.	Total.	Per minute.	Per kilogram per minute.		
d. h. m.		*kilos.*	*mins.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*c.c.*	*mg.*	
6 5	M.	2.70	173	5,707	32.9	12.18	4,174	24.1	8.92	16.08	0.73
1 2 47	M.	3.—	173	6,470	37.4	12.46	3,844	22.2	7.40	13.34	0.593
3 1 55	M.	2.92	159	6,216	39.09	13.38	3,442	21.64	7.41	13.36	0.55
3 7 22	F.	2.47	171	5,463	31.9	12.91	3,586	20.9	8.46	15.25	0.655
7 17 54	M.	2.32	149	4,997	33.5	14.43	2,979	19.9	8.57	15.45	0.59

A very interesting series of experiments on infants was carried out by Scherer, in the institute of Professor Mareš in Prague,[3] with an apparatus on the Regnault-Reiset principle, the oxygen being supplied from a bomb. The author states that the infants found themselves in "complete physiological conditions" inside the chamber. In this series, 55 experiments were made in the spring and summer and 30 experiments in the winter, each one being about 2 hours long. No information is given regarding the activity of the infants or the pulse-rate. The fact that the average respiratory quotients were considerably below 0.6 points strongly to an error in the method. The author concludes that the intensity of the respiratory exchange is dependent upon the body-weight and is inversely proportional to it.

[1]Variot and Lavialle, Bulletins and Mémoires Soc. Med. des Hôpitaux de Paris, 1912, 3d ser., **33**, p. 410. See also Clinique Infantile, 1912, **10**. p. 229, and Report of the Congrès National des Gouttes de Lait ténu à Fécamp les 26, 27, et 28 Mai, 1912, p. 79, for abstracts of this work.

[2]Mensi, Giorn. d. R. Accad. di Med. di Torino, 1894, **57**, p. 301.

[3]Scherer, Jahrb. f. Kinderheilk., 1896, N. F., **43**, p. 471.

Two years later the classic monograph of Rubner and Heubner[1] appeared. In discussing the earlier observations of Forster, they add the significant fact that Forster's experimental periods were but one hour long. As their own work was done with the Pettenkofer chamber, they criticize adversely the closed-circuit apparatus used by Scherer and particularly the fundamental principle of using experiments with short periods, their paper setting forth fully the arguments in favor of the long experimental period and the Pettenkofer type of respiration chamber as compared with the short period and the Regnault-Reiset chamber. The Pettenkofer chamber, which had previously been described,[2] was slightly modified for the studies of Rubner and Heubner, a small chamber being used.

The fundamental question studied by Rubner and Heubner was the nourishment of an infant from a practical standpoint; and they were accordingly more interested in the average daily requirement of an infant for nourishment than in the physiological fact of the minimum requirement for comparison with other individuals. The subject—a "normal" infant—was 9 weeks old at the time of the observation and weighed 5,220 grams. The infant was placed in the respiration chamber and removed and fed from 6 to 8 times each day, the time thus lost being carefully recorded. Ocular observations of the muscular activity were made and a general impression for each day recorded. Much of the time, the infant was awake but not crying. On the basis of 24 hours the authors found a difference of 22 per cent between minimum and maximum carbon-dioxide production. They state that this difference is due to the unequal activity of the infant, emphasizing especially the fact that disturbance of sleep during the night influences the total daily average of the metabolism.

Using Meeh's formula[3] ($S=11.9\sqrt[3]{W}$) and a body-weight of 5.1 kg. they compute the body-surface to be equal to 3,500 sq. cm. and find a carbon-dioxide production of 13.5 grams per square meter of body-surface per hour. Comparing this value with those found with adults, they state that the infant excreted less carbon dioxide per square meter of body-surface than did the adults and explain this by the fact that the infant was asleep a part of the time while the determinations with adults were made only when the subjects were awake. Having pointed out that their results contradict those of Sondén and Tigerstedt,[4] which showed an increased production of carbon dioxide in youth, they emphasize the fact that the carbon dioxide is essentially proportional to the body-surface with human individuals of any size.

Shortly after the publication of their investigations with a normal, breast-fed infant, Rubner and Heubner[5] reported a comparative study

[1]Rubner and Heubner, Zeitschr. f. Biol., 1898, **36**, p. 1.
[2]Wolpert, Archiv f. Hyg., 1896, **26**, p. 32.
[3]Meeh, Zeitschr. f. Biol., 1879, **15**, p. 425.
[4]Sondén and Tigerstedt, Skand. Archiv f. Physiol., 1895, **6**, p. 1.
[5]Rubner and Heubner, Zeitschr. f. Biol., 1899, **38**, p. 315.

with a normal and an atrophic infant, neither being breast-fed. This study was carried out on the same plan as that used for the former experiment. The "normal" infant weighed 7.57 kilograms, was 7½ months old, and appeared to be in good health. She was fed on milk and milk sugar and throughout the observation was said to be in general "*recht ruhig.*" The results were compared with those obtained with the breast-fed infant in the previous experiment, the hourly excretion of carbon dioxide per square meter of body-surface being but 13.5 grams for the breast-fed infant, which weighed but 5 kilograms, and 17.3 grams for the artificially fed infant, which weighed 7.6 kilograms.

TABLE 4.—*Results of experiments with a normal infant and an atrophic infant.* (Rubner and Heubner).

Description of subject.	Food.	Period.	Calories per square meter of body-surface.
Normal.....	Breast-fed.	....	1,006
	Cow milk.	I	1,143
	"	II	1,233
	"	III	1,378
Atrophic....	"	I	1,090
	"	II	1,171
	Meal.	....	1,036

The second portion of the paper deals with the metabolism of the atrophic infant, artificially fed with cow's milk and "*Kindermehl.*" Their results are given in table 4. The authors conclude that there was nothing abnormal in the metabolism of the atrophic infant.

TABLE 5.—*Results of experiments on the respiratory exchange of atrophic infants* (Poppi).

Name.	Date.	Duration.	Body-weight.	Age.	Carbon dioxide produced. Total.	Carbon dioxide produced. Per 24 hours.	Carbon dioxide produced. Per kg. per minute.	Oxygen produced. Total.	Oxygen produced. Per 24 hours.	Oxygen produced. Per kg. per minute.	Respiratory quotient.
	1899.	*h. m.*	*kilos.*	*mos.*	*c.c.*	*liters.*	*c.c.*	*c.c.*	*liters.*	*c.c.*	
P.L.	July 11	1 15	3.425	9	2,166	40.62	8.237	2,084	40.02	8.114	1.015
N.B.	20	2 0	3.865	10	3,900	46.80	8.409	3,820	45.84	8.236	1.021
C.F.	Nov. 10	2 0	5.500	16	4,125	49.50	6.25	4,621	55.452	7.002	0.893
A.F.	12	2 0	3.465	7	3,177	38.13	7.642	3,027	36.324	7.280	1.050
M.G.	15	2 0	5.450	12	4,071	48.852	6.225	4,186	50.232	6.40	0.973
F.G.	Dec. 8	2 0	2.780	3½	2,667	32.004	8.07	2,642	31.704	7.92	1.019
	1900.										
E.N.	Feb. 3	2 0	3.940	4	3,009	36.108	6.364	3,223	38.676	6.818	0.933

The first extensive study exclusively with atrophic infants was made by Poppi.[1] A respiration apparatus of the closed-circuit type was probably used, as both the carbon-dioxide production and the oxygen consumption were measured, though little is said of the method. An abstract of the results obtained with 7 infants is given in table 5.

[1]Poppi, Il ricambio materiale e il ricambio respiratorio nell'atrofia infantile, Bologna, 1900.

The respiratory quotients all seem unusually high, and this fact throws doubt upon the accuracy of the research. It is probable, however, that the carbon-dioxide determinations are well within the limits of accuracy, as is usual with methods of this type. From the protocols of one of Poppi's studies it appears that the experiments were each 2 hours long, but no estimations are given regarding the muscular activity or the pulse-rate.

In 1904 Rubner and Heubner[1] reported another series of experiments covering a period of 5 days. The subject was a breast-fed infant, 5½ months old and weighing 9.7 kilograms. Notwithstanding the apparently large changes in the activity from day to day, the investigators found that the carbon-dioxide output on the last 4 days was fairly constant—a fact which puzzled the authors, who suggest a compensatory influence in the life of the infant. They compare the results found in this observation with those secured with other infants in the previous work done by them, and find an increase in the carbon-dioxide output of 21 per cent over the results obtained with the breast-fed infant previously studied. (See table 6.) This increase they explain by saying that it is due to the greater activity of the infant in the last experiment.

TABLE 6.—*Metabolism of infants compared* (Rubner and Heubner).

Subjects and diet.	Body-weight.	Calories per square meter of body-surface per day.
	kilos.	
Atrophic child (cow milk)	3	1,090
Breast child	5	1,006
Child (cow milk)	8	1,143
Child (breast, of this experiment)	10	1,219

In 1908 a report appeared of the first in a remarkable series of experiments carried out by Schlossmann and Murschhauser in Düsseldorf.[2] The protocols of this experiment were given in connection with a description of the testing of the modified Regnault-Reiset apparatus constructed by Zuntz and Oppenheimer. The authors, Schlossmann, Oppenheimer, and Murschhauser, emphasize the importance of observations when the infant is asleep; they accordingly preferred to make their observations the first half of the night, feeding the infant with a large amount of breast milk in the early evening. The measurements of the metabolism of the infant during this experiment are given in table 7. During the experimental period the infant weighed 5.79 kilograms, the calculated body-surface being 0.384 square meter (using Meeh's formula given on page 15).

[1]Rubner and Heubner, Zeitschr. f. exp. Path. u. Therapie, 1904–05, **1**, p. 1.
[2]Schlossmann, Oppenheimer, and Murschhauser, Biochem. Zeitschr., 1908, **14**, p. 385.

The same infant was subsequently studied by Schlossmann and Murschhauser[1] at the ages of 144 days, 284 days, and 380 days. They found no difference in the metabolism per square meter of body-surface and conclude that Rubner's law is correct and that the metabolic processes are proportional to the body-surface.

TABLE 7.—*Metabolism of an infant* (Schlossmann and Murschhauser).

(Per square meter of body-surface per hour.)

	Oxygen consumption.	Carbon-dioxide production.
	gms.	*gms.*
Average during 8 hours sleep...	11.0	13.78
Shortly after feeding..........	11.88	15.52
Three hours after feeding......	10.42	12.68
Waking and sleeping..........	12.85	15.75

The report of the first extensive research made by Schlossmann and Murschhauser appeared in 1910.[2] This is of special interest, inasmuch as the authors recognize at the outset the importance of muscular repose and of determining the basal metabolism. Many valuable suggestions as to the selection of infants for such study are incorporated in the report. Observations were made on 3 female infants; the results of these are given in table 8. The authors conclude that the carbon-dioxide production and the oxygen consumption depend upon the body-surface, being wholly independent of the age of the subject, and draw the general conclusion that the infant produces per square meter of body-surface about 12 grams of carbon dioxide and consumes about 11 grams of oxygen per hour.

TABLE 8.—*Results of fasting experiments with infants during approximately absolute rest* (Schlossmann and Murschhauser).

Subject.	Age.	Weight.	Body-surface.	Carbon-dioxide per square meter per hour.	Oxygen per square meter per hour.	Respiratory quotient.
	days	*kilos.*	*sq. m.*	*grams.*	*grams.*	
S........	174	5.010	0.3505	12.27	10.56	0.847
	180	5.115	.3553	12.22	10.81	.824
P........	149	4.220	.3124	12.35	10.52	.856
	169	4.430	.3228	12.64	11.08	.832
L........	87	4.980	.3491	12.33	12.22	.730
	93	5.040	.3519	11.48	10.93	.760

Recognizing the possibility that the environmental temperature may have an effect upon the metabolism of the infant, Schlossmann and Murschhauser discussed this point in 1911,[3] giving the results of experiments with an infant in which the temperature of the surrounding atmosphere varied from 16.3° C. to 23.4° C. Another infant was

[1]Schlossmann and Murschhauser, Biochem. Zeitschr., 1909, **18**, p. 499.
[2]*Ibid.*, 1910, **26**, p. 14.
[3]*Ibid.*, 1911, **37**, p. 1.

studied with temperatures varying from 16.9° C. to 23.4° C. The results of this second experiment substantiated those obtained with the first infant, and the authors feel justified in concluding that the slight temperature changes found in experiments with an apparatus of the Regnault-Reiset type are entirely without influence upon the metabolism of the individuals studied.

The same investigators,[1] with a keen appreciation of the influence of muscular activity upon metabolism, compared the results of observations with an infant who cried continuously for an hour with those obtained when the infant was approximately quiet. They estimated that the crying increased the carbon-dioxide production 59.4 per cent and the oxygen consumption 44 per cent.

In still another paper Schlossmann[2] discusses the general principles involved in the measurement of the respiratory exchange of infants and emphasizes the necessity of muscular repose and the absence of food, and the importance of measuring the basal metabolism. He again asserts that the heat per square meter of body-surface is constant and maintains that this is a proof that the metabolism of young individuals is not variable. In this paper, also, he discusses the amount of work the infant does, basing the discussion upon results obtained in his experiments with crying infants. In many of his experiments Schlossmann measured the skin-temperature of the infant by electrical methods and found that there was no increase in the temperature.

In a paper discussing his earlier experiments on infants of varying ages and particularly those with an atrophic infant, Schlossmann opposes the views defended by Kassowitz[3] that the metabolism in smaller animals is more intense than in the large animals and that there is no relationship between the metabolism and the body-surface.[4] Schlossmann maintains that atrophic infants have a higher metabolism per unit of body-surface than normal infants, but that this points to the correctness of the Rubner law, since with these infants the relation between body-surface and body-weight is abnormal. As he made no measurements of the body-surface of these infants—a procedure that necessitated an enormous amount of work—no direct evidence is offered to show that there was an actual disproportion between the body-surface and the body-weight.

In a paper which appeared after the publication of Schlossmann's criticism, Kassowitz[5] sums up his arguments against the belief that the metabolism is proportional to the body-surface and using Schlossmann's own protocols criticizes adversely the latter's deductions.

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[1]Schlossmann and Murschhauser, Biochem, Zeitschr., 1911, 37, p. 23.
[2]Schlossmann, Deutsche med. Wochenschr., 1911, **37**, p. 1633.
[3]Kassowitz, Allgemeine Biologie, Vienna, 1904, **3**, p. 221.
[4]Schlossmann, Zeitschr. f. Kinderheilk., 1912–13, **5**, p. 227.
[5]Kassowitz, Zeitschr. f. Kinderheilk., 1913, **6**, p. 240.

In a paper which has only recently appeared[1] Schlossmann again discusses the degree of activity and the amount of work done by infants in crying. He strongly emphasizes the necessity of noting the degree of repose during the observation, either by the ocular method used by himself or the graphic record devised in this laboratory. Unfortunately at the time this paper was written, Schlossmann had not been able to compare the two methods.

Two later communications by Schlossmann and Murschhauser[2] on the metabolism of fasting infants have particular significance in connection with this report, as they discuss the ideal conditions for obtaining the basal metabolism.

Using a Pettenkofer-Voit respiration apparatus[3] in the Kaiserin Auguste Victoria-Haus in Charlottenburg, Birk and Edelstein[4] studied the respiratory exchange of a healthy, new-born infant weighing 3.2 kilograms and having a length of 50 cm. The infant was completely wound in cotton wool so as to keep the body-temperature at a normal level. Although he was removed from the respiration chamber several times during the day, the infant remained in the apparatus for the greater part of the 24 hours. On the second day the carbon-dioxide production per 24 hours was 55.6 grams, or 18.2 grams per kilogram; on the third day the total amount was 47.59 grams, or 15.76 grams per kilogram per 24 hours. The authors criticize the use of short experiments with a respiration apparatus by which the oxygen consumption can be determined and the respiratory quotients calculated, but they express regret that with their method the oxygen consumption can not be determined.

In a study made by Carpenter and Murlin of the energy metabolism of pregnant women before and after the birth of the child,[5] the energy metabolism of three new-born infants was also found per unit of weight and per unit of body-surface. The values were obtained by subtracting the measured metabolism of the mother from that of the mother and infant.

The metabolism of an atrophic infant was studied by Niemann,[6] who used a Pettenkofer-Voit respiration apparatus in the children's clinic of the University of Berlin. The observation continued 6 days, the infant remaining in the chamber the greater part of each day. The measurements of the carbon-dioxide production on the basis of 24 hours are given in table 9. When these results are computed on the basis of carbon dioxide produced per square meter of body-surface,

[1]Schlossmann, Monatsschr. f. Kinderheilk., 1913, **12**, p. 47. See also Am. Journ. Diseases of Children, 1913, **6**, p. 15.
[2]Schlossmann and Murschhauser, Biochem. Zeitschr., 1913, **56**, p. 355, *ibid.*, 1914, **58**, p. 483.
[3]Bahrdt and Edelstein, Jahrb. f. Kinderheilk., 1910, **72**, p. 43.
[4]Birk and Edelstein, Monatsschr. f. Kinderheilk., 1910, **9**, p. 505.
[5]Carpenter and Murlin, Arch. Internal Med., 1911, **7**, p. 184.
[6]Niemann, Zeitschr. f. Kinderheilk., 1913, **6**, p. 375.

using the formula of Meeh and the constant 11.9, the author finds that this infant with an average body-weight during the 6 days of 3.28 kilograms had a body-surface corresponding to 0.2626 square meter, and that the carbon-dioxide excretion per square meter of body-surface was 18.5 grams per hour.

Table 9.—*Results of an experiment with an atrophic infant* (Niemann).

Day.	Carbon-dioxide production per day.	Average temperature of air.
	grams.	°*C.*
1	108.0	20.5
2	110.4	20.0
3	117.6	21.0
4	115.2	21.0
5	120.0	21.0
6	127.2	21.0
Maximum	127.2	....
Minimum	108.0	....
Average	116.4	....

The metabolism of another atrophic infant was studied in the Universitäts-Kinderklinik, Berlin, by Frank and Wolff.[1] Using the Pettenkofer-Voit respiration apparatus modified by Rubner, they made two series of experiments of 4 days each. The average values for carbon dioxide are given in table 10. The authors especially comment upon

Table 10.—*Average carbon-dioxide excretion in experiments with an atrophic infant* (Frank and Wolff).

	Period I.	Period II.
Total 24 hours	127.61	148.81
Per hour	5.317	6.151
Per kilogram per 24 hours	34.44	38.95
Per kilogram per hour	1.435	1.623
Per square meter per hour	18.76	21.26

the unusually high figures for the carbon-dioxide excretion and attempt to explain them by the disturbance between the computed body-surface and body-weight and the effect of a protein-rich diet, but expressly maintain that muscular activity played no rôle, as the infant, except on the first day, was "*sehr ruhig.*"

Bahrdt and Edelstein[2] also report an experiment with an atrophic infant, in which they used the respiration apparatus in Langstein's laboratory in the Kaiserin Auguste Victoria-Haus. The observation was made in three periods of four days each. In the first and last periods, the infant remained inside the chamber for the greater part of the 24 hours, being removed periodically, as is customary in experiments with this type of apparatus. Their final conclusion was that the heat-

[1]Frank and Wolff, Jahrb. f. Kinderheilk., 1913, **78**, p. 1.
[2]Bahrdt and Edelstein, Festschrift Dr. Otto L. Heubner, Berlin, 1913.

production of atrophic infants can be abnormally high aside from any effect which the environmental temperature or the body activity may have upon it.

Finally the direct calorimetric and gasometric researches of Howland[1] in Lusk's laboratory should be especially noted. In discussing the calculation of the body-surface, Howland cites the use of the factor 12.3 as a constant for infants, but we are not aware of any writers who have previously used this factor. The experiments were made with the respiration calorimeter[2] at the Cornell University Medical College in New York. Three infants under one year of age were studied and ocular observations of the activity of the infants were recorded.

Howland's experiments were subsequently published in detail and the results more fully discussed.[3] In this paper the relationship between body-surface and body-weight is extensively treated and the various factors and formulas are considered. A curve is proposed which is represented by the algebraic expression $y = mx + b$, in which y is the surface area of the infant, x the weight of the infant in grams, m the constant 0.483, and b 730 sq. cm.

Table 11.—*Heat-production of infants, directly and indirectly measured, as reported by Howland.*

Subject.	Food.	Calories per square meter per day.		Difference (per cent).
		Measured.	Calculated.	
Child 1	Ordinary	1,046 1,113 1,196	1,084 1,174 1,164	2
Do	Nutrose added	1,218	1,179	3
Do	do	1,204 1,235 1,181	1,180 1,212 1,250	Less than 1
Do	Fasting	1,106 1,226 1,301	1,177 1,156 1,243	Less than 1
Child 3	Ordinary	858 913	793 933	2
Do	do	825	840	2

The last portion of the paper, which is of most significance, compares the direct and indirect computation of the heat-production of the infants observed. This comparison is of such value to workers in metabolism that it is given here in table 11. The agreement between the heat-production as directly measured and as indirectly computed is striking, to say the least, and justifies for the present the utilization of the indirect method of computing the calorimetry of infants.

[1]Howland, Proc. Soc. Exp. Biol. and Med., 1911, 8, p. 63; Hoppe-Seyler's Zeitschr. f. Physiol. Chem. 1911, **74**, p. 1.
[2]Williams, Jour. Biol. Chem., 1912, **12**, p. 317.
[3]Howland, Trans. 15th Int. Congress on Hygiene and Demography, Washington, 1913, **2**, p. 438.

BASIC PRINCIPLES.

Though Howland, using Lusk's calorimeter, has been eminently successful in experiments on the direct calorimetry of infants, experience with such researches in the Nutrition Laboratory has led us to believe that a type of calorimeter with less mass, less heat capacity, and probably not of the continuous-flow type could most advantageously be employed for the short periods necessitated by experiments with infants. Several types or modifications of calorimeters have been in process of testing for some time, and pending the satisfactory development, construction, and testing of an infant calorimeter with the qualifications referred to, we have actively undertaken the study of infant metabolism as determined by indirect calorimetry. In these observations we have devoted our energies to the accurate measurement, in relatively short periods, of the carbon dioxide produced and oxygen consumed by infants less than one year of age.

There is at present in America a strong movement toward the development of hospital clinics liberally endowed for scientific research and it is fair to assume that in the next decade the study of infant metabolism will be more actively prosecuted in this country than ever before. Clinicians with whom we have conferred have especially requested that in publishing the results of our observations we should discuss the gaseous metabolism of infants somewhat in detail. Accordingly at this point it seems desirable to define a few of the principles underlying the method of study. This is done, first, to make clear the methods and technique used in our investigation; and, second, to serve as a guide for those clinicians or experimenters who are interested in actively following this line of research.

THE RESPIRATORY QUOTIENT AND ITS SIGNIFICANCE.

The oxygenation of the blood—which, prior to the birth of an infant, was effected by the lungs of the mother—is after birth at once begun through the lungs of the infant. The oxygen is carried by the blood to the various tissues and there enters into the katabolic processes, oxidizing the protein, fat, and carbohydrates. The resulting carbon dioxide is carried by the blood to the lungs and thence excreted into the air which passes though the lungs in respiration, while the partially oxidized nitrogenous products resulting from protein disintegration are excreted through the kidneys. With normal life both the carbohydrates and fat of the body-material are converted into carbon dioxide and water; protein, also, is in large part changed to carbon dioxide and water, the nitrogenous portion being excreted in the urine in the form of urea, uric acid, and allied compounds.

The chemical composition of the chief constituents of the body has been determined by analysis and is given in table 12. These values

represent the average of a large number of analyses, and have been extensively used in computations of the indirect calorimetry of men.

TABLE 12.—*Chemical composition of the constituents of the body.*[1]

Body material.	N.	C.	H.	O.	Mineral matters (including S.).
	per cent.	*per cent.*	*per cent.*	*per cent.*	*per cent.*
Proteins	16.67	52.80	7.00	22.00	1.53
Fat	....	76.10	11.80	12.10	....
Carbohydrate (glycogen)	....	44.40	6.20	49.40	....

[1]While these values were determined on carefully isolated and purified materials obtained from the animal body, they may be considered as approximate values for all proteins and fats.

Innumerable analyses have been made of the ordinary food substances, but the composition of starch, cane sugar, glucose, and lactose can be computed from the chemical formulas directly. For the composition of normal fat, the average values given by Koenig are ordinarily used.[1] When these substances are burned inside the body, a definite volume of oxygen combines with their carbon and hydrogen to produce carbon dioxide and water. The amount of carbon dioxide produced per gram of a substance, the amount of oxygen required for the oxidation, and the total heat evolved can be determined exactly by burning a known amount of various fats and carbohydrates outside of the body, as, for instance, in a calorimetric bomb.

The carbon dioxide is excreted in a gaseous form, while the water may be excreted through the kidneys, vaporized through the lungs and skin, or added to the residual water always present in the body. Since there is so large a storage of water in the body, it is obviously impossible to distinguish between water formed by the oxidation of organic material and water existing preformed in the body, but the relationship between the oxygen consumed and the carbon dioxide produced has a great physiological value and plays an important rôle in indicating the *character* of the material burned in the body. The importance of this relationship was early recognized by Pflüger and the ratio was designated by him as the "respiratory quotient."

The theoretical respiratory quotient for the combustion of a pure substance of definite chemical composition may be easily computed. If we consider, for example, one of the chief foods of an infant—lactose or milk sugar, with a chemical formula of $C_{12}H_{22}O_{11} + H_2O$—we see that the hydrogen and oxygen are present in the molecule in the exact proportions to form water. Since there is in the molecule sufficient oxygen to oxidize the hydrogen completely, the oxygen which enters into the combustion burns only the carbon. It is, of course, obvious that the complete combustion does not proceed in this sharply defined manner, but this alters in no wise the trend of our reasoning.

[1]Koenig, Chemie der menschlichen Nahrungs- und Genussmittel, 3d ed., **1**, p. 198.

The chemical reaction may be expressed as follows:

$$C_{12}H_{24}O_{12} + 12\ O_2 = 12\ CO_2 + 12\ H_2O$$

That is, for every 12 molecules of oxygen absorbed, there are produced 12 molecules of carbon dioxide. Accordingly, for every liter of oxygen absorbed, there is produced one liter of carbon dioxide, so that the volume ratio may be expressed:

$$\frac{\text{Volume } CO_2}{\text{Volume } O_2} = 1.00$$

We can say, therefore, that the respiratory quotient of lactose is 1.00. This is also true of all carbohydrates, including starch, cane sugar, levulose, and dextrose.

Furthermore, it can be computed from the molecular composition that 1 gram of human fat requires 2.844 grams of oxygen in its combustion and that as a result of the combustion 2.790 grams or 1,420.4 c.c. of carbon dioxide are produced. There is, therefore, an absorption of 1,990.8 c.c. of oxygen to form 1,420.4 c.c.[1] of carbon dioxide; hence the respiratory quotient would be:

$$\frac{\text{Volume } CO_2}{\text{Volume } O_2} = \frac{1420.4}{1990.8} = 0.713.$$

The calculation of the theoretical respiratory quotient of protein is less simple, owing to the fact that protein is only incompletely oxidized, a portion of the protein molecule being excreted unburned in the form of urea, uric acid, and allied compounds in the urine. The calculation of this quotient has been made in a number of ways by different writers on the subject, each assuming a somewhat different molecular composition for protein and each ascribing in turn various values to the

TABLE 13.—*Assumed apportionment of elements after oxidation.*

	C.	H.	O.	N.	S.
	grams.	*grams.*	*grams.*	*grams.*	*grams.*
In the urine.....	9.406	2.663	14.099	16.28	1.02
In the feces......	1.471	0.212	0.889	0.37	0.00
Remainder......	41.500	4.400	7.690	0.00	0.00

unoxidized portion of the protein excreted in the feces as well as in the urine. Furthermore, observers differ as to what degree the sulphur of protein is oxidized, for unoxidized as well as completely oxidized sulphur may be found in the urine. The following calculation is taken directly from Loewy,[2] in which he assumes that 100 grams of fat-free, dry substance of flesh contain 52.38 grams of carbon, 7.27 grams of hydrogen, 22.68 grams of oxygen, 16.65 grams of nitrogen, and 1.02 grams of sulphur. The assumed apportionment after oxidation is given in table 13.

[1]Erroneously stated as 1,240.4 c.c. by Benedict, Am. Journ. Physiol., 1909, **24**, p. 348.
[2]Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, **4**, (1) p. 156.

In the combustion of 41.5 grams of carbon and 4.4 grams of hydrogen, 145.87 grams of oxygen are used. Deducting from this the 7.69 grams originally in the protein and not excreted in the urine or feces, 138.18 grams of oxygen additional are required. During the process of oxidation, 152.17 grams of carbon dioxide are formed. Reducing these values to volumes, we then have the ratio:

$$\frac{\text{Volume } CO_2}{\text{Volume } O_2} = \frac{77.39}{96.63} = 0.801.$$

The oxygen required for combustion, the products of combustion, and the respiratory quotient for several typical materials have been calculated and are given in table 14.

TABLE 14.—*Respiratory quotients for protein, fats, and carbohydrates.*

Materials.	Oxygen required to oxidize 1 gram.		Produced in the oxidation of 1 gram.			Respiratory quotient $\frac{CO_2 \text{ c.c.}}{O_2 \text{ c.c.}}$
			Carbon dioxide.		Heat.	
	Weight.	Volume.	Weight.	Volume.		
	grams.	*c.c.*	*grams.*	*c.c.*	*cal.*	
Starch	1.185	829.3	1.629	829.3	4.20	1.000
Cane sugar	1.122	785.5	1.543	785.5	3.96	1.000
Milk sugar[1]	1.066	756.2	1.466	746.2	3.75	1.000
Animal fat	2.876	2013.2	2.811	1431.1	9.50	0.711
Human fat	2.844	1990.8	2.790	1420.4	9.54	0.713
Protein[2]	1.367	956.9	1.520	773.8	4.40[3]	0.809

[1] These values apply likewise to dextrose and levulose.

[2] While this computation is based upon meat protein, the values will be essentially the same for all proteins. These values represent quantities found when burning protein not in a calorimetric bomb, but in the animal body.

[3] The heat of combustion of protein averages 5.65 calories per gram; deducting the unoxidized material in the urine, the heat per gram would be 4.40 calories. For discussion of this point, see Atwater and Bryant, Storrs (Connecticut) Agr. Expt. Sta. Rept., 1899, p. 73.

The carbohydrates have a respiratory quotient of 1.00; fat in general, of 0.71; and protein of 0.81. From these factors, therefore, we can see that during inanition, when the subject is subsisting for the greater part upon body-fat and protein, the respiratory quotient would tend to approach 0.71. On the other hand, if a diet is taken consisting largely of carbohydrates, the respiratory quotient tends to approach 1.00.

Since the metabolism of the protein remains relatively constant from day to day and from hour to hour and is but a small proportion of the whole, the errors involved in its calculation are not of sufficient magnitude to influence seriously any deduction drawn from the results in which these calculations occur. Usually the disintegration of the protein is about 15 per cent of the total katabolism. Magnus-Levy[1] has calculated that if the remaining 85 per cent is wholly from carbohydrates, the respiratory quotient would be 0.971; if, on the other hand, the remainder of the energy is derived solely from fat, the respiratory

[1] Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1896, 1, p. 217.

quotient would be 0.722.[1] Under ordinary conditions, the respiratory quotient would lie between these two figures, and values above or below these points might reasonably be considered as due to faulty technique, to distinctly abnormal metabolism, or to a possible formation of fat from carbohydrate or carbohydrate from fat.

It is thus clear that when the respiratory quotient is carefully determined, considerable light may be thrown upon the *character* of the materials burned in the body. It should be considered, however, that to determine accurately the respiratory quotient calls for an extraordinarily skilful technique, since any errors affecting either the determination of the carbon dioxide or the determination of the oxygen likewise affect the respiratory quotient.

The absolute values for the amounts of carbon dioxide exhaled and oxygen absorbed in a given time, usually 1 minute, 1 hour, or 24 hours, are also of importance in indicating the quantitative relations of the total katabolism. For example, it is possible to strike a daily balance from the amounts determined for 24 hours and show the adequacy or inadequacy of the ration for maintenance by determining or computing the carbon in the diet.

INDIRECT CALORIMETRY.

A number of physiologists have used the respiratory exchange to compute the total calorimetry by the method of so-called "indirect calorimetry,"[2] and obtained results of still more importance. The total katabolism may be apportioned between protein, fat, and carbohydrates by using the determination of nitrogen in the urine (protein katabolism) and the respiratory exchange. Since in calculating the materials katabolized in experiments with respiration calorimeters, it is generally assumed that all of the food materials are first transformed into similar substances found in the body, the calculation of the total energy may with propriety be based upon the values of body-protein, human fat, and glycogen. As each of these materials, when burned, supplies definite amounts of heat, the total energy resulting from the oxidation may be computed by multiplying the number of grams of each katabolized material by certain factors, that customarily used for protein being 5.65, or after deducting the potential energy in the urine, 4.4; for fat, 9.54; and for carbohydrates, 4.19.

Definite information regarding the calorific output of an infant is of great importance in studying infant nutrition in order that a calculation may be made of the amount of food required to provide a suitable quota of calories for the day. The caloric losses from the body, therefore,

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[1]Erroneously reported as 0.772 by Benedict, Am. Journ. Physiol., 1909, **24**, p. 351.

[2]This method is not to be confused with the usage of certain French writers who consider "indirect calorimetry" as indicating the computation of material consumed by noting the weights of food eaten, excreta, and gain or loss of body-weight.

require careful consideration in studies of infant metabolism. With normal metabolism and normal digestion, the loss of unoxidized material in the feces and urine may be considered as essentially constant. The feces represent not merely the undigested residues of food but the epithelial débris, the residues of digested juices, and bacteria; with normal digestion, these remain essentially a constant percentage of the total amount digested.

It is not the loss of energy through the urine and feces, however, that is of special interest in studying infant metabolism, but the losses resulting from the katabolism of materials in the body, namely, the loss through the combustion of organic substances by virtue of the oxygen taken into the system and there combined with carbon and hydrogen to form carbon dioxide and water. The carbon dioxide thus formed has been considered so close a measure of the total amount of material burned that for years it served as the index of the total combustion of the materials in the body. It may be computed from the data given in table 14 that if the combustion in the body were exclusively of carbohydrate, the production of 1 liter of carbon dioxide would be equivalent to the liberation of approximately 5.05 calories of heat. If, on the other hand, the carbon dioxide resulted exclusively from the combustion of fat, it can be computed that 1 liter of carbon dioxide corresponds to 6.7 calories of heat.

While with an infant on a normal diet the proportions of protein, fat, and carbohydrate in the oxidized material may remain relatively constant, it is certainly true that in pathological cases these proportions may be greatly disturbed, and the calorific value of the carbon dioxide may vary considerably with different conditions. Inasmuch as information regarding the diet and treatment of infants is more especially required in pathological conditions, it is evident that a better method for estimating the total heat output than by the carbon-dioxide excretion is to be desired. If the relationship between the heat-output and the oxygen consumption is closely examined, it will be seen that the ratio is much more constant than is the ratio between the carbon dioxide and the heat. Thus, for every gram of lactose burned, 1.066 grams of oxygen are consumed, each gram of oxygen thus used being equivalent to 3.51 calories of heat. Likewise, for every gram of fat burned, 2.85 grams of oxygen are consumed, each gram of oxygen resulting in the production of 3.35 calories of heat. It will be seen from these figures that while the calorific equivalent of carbon dioxide varies some 25 per cent according to whether carbohydrate or fat is burned in the body, the calorific equivalent of oxygen varies only about 6 per cent. It is clear, therefore, that the best measurement of the caloric output of the body is the amount of oxygen consumed rather than the amount of carbon dioxide produced.

With modern apparatus it is possible to arrive at an even more exact knowledge of the energy output by determining both the oxygen consumption and the carbon-dioxide production and calculating the respiratory quotient. Zuntz, to whom we are especially indebted for the introduction of this method for computing the heat output, has painstakingly computed the calorific value of oxygen with different respiratory quotients, and these figures may be considered to-day as the best data that we have for the computation of the energy output from the measurement of the gaseous exchange. In the Zuntz laboratory, where practically all of the experiments carried out have been made upon adults with a mouthpiece or upon animals with tracheal fistulas, the

TABLE 15.—*Calorific equivalents of carbon dioxide.*

Respiratory quotient.	Calorific value of carbon dioxide.		Respiratory quotient.	Calorific value of carbon dioxide.		Respiratory quotient.	Calorific value of carbon dioxide.	
	Per liter.	Per gram.		Per liter.	Per gram.		Per liter.	Per gram.
	cals.	*cals.*		*cals.*	*cals.*		*cals.*	*cals.*
0.70	6.694	3.408	0.80	6.001	3.055	0.90	5.471	2.785
.71	6.606	3.363	.81	5.942	3.025	.91	5.424	2.761
.72	6.531	3.325	.82	5.884	2.996	.92	5.378	2.738
.73	6.458	3.288	.83	5.829	2.967	.93	5.333	2.715
.74	6.388	3.252	.84	5.774	2.939	.94	5.290	2.693
.75	6.319	3.217	.85	5.721	2.912	.95	5.247	2.671
.76	6.253	3.183	.86	5.669	2.886	.96	5.205	2.650
.77	6.187	3.150	.87	5.617	2.860	.97	5.165	2.629
.78	6.123	3.117	.88	5.568	2.835	.98	5.124	2.609
.79	6.062	3.086	.89	5.519	2.810	.99	5.085	2.589
						1.00	5.047	2.569

determinations of the oxygen consumption are as accurate as are those of the carbon-dioxide production; consequently Zuntz has utilized the calorific values of oxygen, and these have been given in tabular form in one of the publications from his laboratory.[1] Knowing the respiratory quotient, the calculation of the calorific value of carbon dioxide is a simple one. Since, in our respiration apparatus, the carbon-dioxide determinations for short periods are even more exact than are the determinations of the oxygen, we give in table 15 the calorific equivalents of carbon dioxide with the varying respiratory quotients, particularly as this table will be used extensively in the computation of our own researches.

Since any form of indirect calorimetry must of necessity be somewhat speculative,[2] one must always rely for fundamental values upon direct heat measurements. Such measurements have been extensively made

[1]Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 361.

[2]It will be noted that in this publication the computation of the energy derived from protein is neglected and that the total energy output is computed only from the amounts of carbon dioxide and oxygen. The possible error in neglecting the protein has been computed by Magnus-Levy to be somewhat under 1 per cent, and as the determinations of nitrogen were not feasible in our studies, we have used the method of simple computation from the gaseous exchange as recommended by A. Loewy. (Loewy, Oppenheimer's Handbuch der Biochemie, Jena, 1911, **4**, p. 281. See also, Magnus-Levy, von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 1896, **1**, p. 207.)

with men by Atwater and his associates at Wesleyan University, Middletown, Connecticut, where it was shown in experiments of long duration that the heat output as measured directly by the respiration calorimeter and the heat output as computed from the respiratory exchange agreed remarkably well. It should be pointed out, however, that these computations were based upon 24-hour periods. In certain experiments the computation has likewise been successful for periods as short as 6 hours, but it remained for Howland[1] to demonstrate with Lusk's calorimeter the complete agreement of the direct calorimetric measurements and of the computation from the gaseous exchange for short periods and particularly with an infant as subject.

Howland has, temporarily at least, forsaken direct calorimetric research, as he is not now supplied with a respiration calorimeter, but it is much to be hoped that these few observations, which imply such a remarkable agreement between the direct and indirect calorimetry, may be extended in the near future to cover other cases. Until later evidence disproves this assumption, workers in this field are perfectly justified in assuming that the comparison between direct and indirect calorimetry has been made with infants with more than ordinary scientific accuracy. This being the case, the field is open for making a large number of metabolism experiments with the respiration apparatus in laboratories and institutions where a respiration calorimeter for direct calorimetry is not available.

BASAL METABOLISM.

While the normal life of the infant is a relatively simple and constant one, yet it does include periods of muscular activity which vary greatly, the extremes ranging from perfect muscular repose during deep sleep to the violent exercise incidental to vigorous crying. As a result of these changes in muscular activity, the output of heat would likewise vary largely, with a minimum output during sleep and quiet and a maximum during the period of crying. An attempt has been made to find the average value for the heat output of an infant by experiments with 24-hour periods, thus securing an average for the life of the day; but when one considers that the difference between the heat output in complete muscular repose during sleep and the heat given off when the infant is crying vigorously may be as great as 60 or more per cent, it will be seen that this method of averaging does not furnish information with regard to the minimum metabolism.

With adults, the best condition which has been found for a basis of comparison has been when the subject was in complete muscular repose and in the so-called "post-absorptive" state, *i. e.*, when absorption of material from the alimentary tract had ceased, this being with adults generally 12 hours after the last meal. With an adult who is capable of a certain degree of muscular relaxation and repose, suitable experi-

[1]Howland, Trans. 15th Int. Congress on Hygiene and Demography, Washington, 1913, **2**, p. 451.

mental conditions can be obtained without great difficulty. With an infant this condition may only be approximated during sleep. It thus becomes necessary to consider seriously a fundamental change in the principle of studying infant metabolism and, instead of attempting to average the life during a 24-hour period, to use only selected periods with complete muscular repose.

The muscular activity of infants is twofold: (1) internal muscular activity, consisting of muscular tonus, the movements of the organs of circulation and respiration, and possibly the processes of digestion; and (2) external muscular activity such as the movements of the limbs or vigorous body movement incidental to crying. The internal movements can be controlled only by minimizing the after-effects of digestion through the absence of food; the regular involuntary muscular activity of the respiratory and circulatory system and the muscular tonus can not be altered. On the other hand, the external muscular activities are at a minimum only during complete muscular repose, as in deep sleep. It is thus seen that the ideal conditions for studying the basal or minimum metabolism of infants would be the post-absorptive state—that is, sufficiently long after the last meal to insure that there was no longer an absorption of food materials from the alimentary tract, and during deep sleep when there is complete muscular repose. With very young infants, periods of complete muscular repose can not be expected for any great length of time, probably not for more than two successive hours.

The difficulties incidental to securing these conditions have prevented researches in this line for many months, if not years; the best method for obtaining them is still to be demonstrated.

We have, then, two factors to deal with, first, the heat elimination incidental to the specific katabolic stimuli of the food materials accompanying the digestion and absorption of food; and, second, the internal muscular activity of the infant. If the first of these factors can be eliminated, we have what may properly be termed the basal metabolism unaccompanied by extraneous muscular activity of any kind.

APPARATUS AND METHODS USED IN THIS RESEARCH.

Certain inherent difficulties in conducting experiments with infants have undoubtedly delayed the accumulation of a large amount of material in regard to infant metabolism. While researches have been actively prosecuted with domestic animals and with men for many years, the technique for the study of the metabolism of infants has been but slowly developed. Nevertheless, the natural difficulties incidental to the separation of the urine and feces of children have been for the most part overcome by careful technique, so that in hospital wards, at least, experiments on the total urine and fecal secretions can now be satisfactorily made.

But in a more extensive study of infant metabolism certain difficulties occur which are not encountered in a study of the metabolism

of an adult. The infant is incapable of giving intelligent assistance in the experiment, neither can its muscular activity be controlled. Furthermore, in adult life, growth has been attained and the energy required is mainly for maintenance and for definite external muscular work, while infancy is a period of rapid growth, at least if normal metabolism is progressing; the infant, therefore, requires energy both for growth and for maintenance. While the amount of effective mechanical work is nil, nevertheless it has been clearly demonstrated that, during the periods of muscular activity incidental to the active life of the infant, there may be a large increase in the total metabolism. This simultaneous requirement for growth and for maintenance makes the study of infant metabolism a doubly complicated problem.

On the other hand, in studying the metabolism of an adult, one of the greatest difficulties we have to contend with is the complex life of the normal individual—the irregular or intermittent ingestion of food and the various degrees of muscular activity contributing to the sum total of the metabolic changes of the day. It is possible, by means of large respiration chambers, to approximate the normal life of a man of sedentary occupation or even with some degree of muscular activity, but it is practically impossible to duplicate the life of an ordinary individual with its different environments and activities. Consequently with adults it is necessary to secure periods for observation when the subject is without food in the stomach and when there is a minimum amount of activity. With an infant who spends the greater part of his day in the crib, the life complexes can be much more easily studied. The daily life is divided first into eating, sleeping, and crying; later, as the special senses and the intellect develop, to these divisions are added playing and exercise. Throughout the infantile period, therefore, the daily routine is monotonous and regular, with hours of sleep and waking time relatively constant. The diet of the infant is also unchanging in character, consisting for the most part of milk.

In summing up, we may say that the normal infant is more nearly constant as to its body activity, daily routine, and diet than the normal adult with his higher life complexes. The inability of the infant to assist materially in metabolism experiments, the difficulty of carrying out definite well-known tests with mathematical accuracy, and the impossibility of regulating the muscular activity must therefore be offset by this constancy in diet and daily routine. Hence it is by no means impossible to reproduce the daily routine of infants inside of a specially constructed chamber.

RESPIRATION APPARATUS.

In the Nutrition Laboratory and previously in the chemical laboratory of Wesleyan University, Middletown, Connecticut, various types of apparatus for studying the respiratory exchange have long been in the process of development. Since practically all of the earlier work

had to do with the metabolism of men, there was very little demand for a small respiration apparatus. There are, however, many physiological laboratories and laboratories in hygienic institutes and medical clinics that wish to utilize an apparatus, not only for experiments with men but also with animals. Such a possibility has already been demonstrated, notably by Grafe[1] in Heidelberg and by Rolly[2] in Leipsic. A small apparatus, which is based upon the principle of the large respiration calorimeters used in this laboratory, has been here devised for experiments with men; this has already been described in detail.[3] While the fundamental principle has not been altered in any way, the apparatus has from time to time been modified and improved, and a cage or respiration chamber added, thus making observations possible with small animals and with infants. Its use with animals was first described by Benedict and Homans;[4] it was later referred to in a paper by Benedict and Talbot[5] as being used for observations with infants. In these earlier descriptions, it was stated that the apparatus had been only so far perfected as to permit the measurement of the carbon-dioxide excretion and did not permit the measurement of the oxygen consumption. Since these publications have appeared, a newer type of this apparatus has been devised and at least two investigations[6] have been reported from this laboratory in which the apparatus was used. The large number of respiration apparatus devised in the American and foreign laboratories make it practically impossible to contribute any fundamentally new features to the study of animal metabolism along this line. Nevertheless, as the main object in devising the apparatus used in this laboratory was to make it so flexible that it could be employed not only for men but likewise for infants and for large and small animals, a description of this later form seems desirable before further investigations are reported.

While the new feature in this modified apparatus is the direct determination of the oxygen consumption, opportunity is again taken here to emphasize strongly the importance of graphic records of the muscular activity in experiments with all classes of subjects, including not only men but infants and small animals, and also to emphasize the importance of the pulse-rate as an index of the intensity of the metabolism. Every respiration experiment conducted in this laboratory consists always of two parts, each indispensable to the other and each valueless without the other; first, the chemical division, *i. e.*, the measurements of the carbon-dioxide excretion and the oxygen consumption; and,

[1]Grafe and Graham, Zeitschr. f. physiol. Chem., 1911, **73**, p. 7.

[2]Rolly and Rosiewicz, Deutsch. Archiv f. klin. Med., 1911, **103**, p. 58. See also discussion of Rolly's apparatus by Grafe, Abderhalden's Handbuch der biochemischen Arbeitsmethoden, 1913, **7**, p. 524.

[3]Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 156.

[4]Benedict and Homans, Journ. Med. Research, 1912, **25**, p. 409.

[5]Benedict and Talbot, Am. Journ. of Diseases of Children, 1912, **4**, p. 129.

[6]Benedict and Pratt, Journ. Biol. Chem., 1913, **15**, p. 1; Morgulis and Pratt, Am. Journ. Physiol., 1913, **32**, p. 200. At this point it is a pleasure to acknowledge the helpful assistance of Dr. S. Morgulis in developing the technique of determining oxygen with the apparatus.

second, the graphic records of the muscular activity or muscular repose and the pulse-rate. The main object of the apparatus and its accessories is, therefore, to give an accurate measurement on small animals or infants of the carbon dioxide produced and the oxygen consumed, and an interpretable record of the degree of muscular activity or repose, accompanied by pulse observations.

The carbon dioxide produced by the animal is completely absorbed, the amount excreted being determined by the increase in weight of the absorbing vessels. Gas analyses, with their attendant difficulties of technique, are therefore unnecessary.

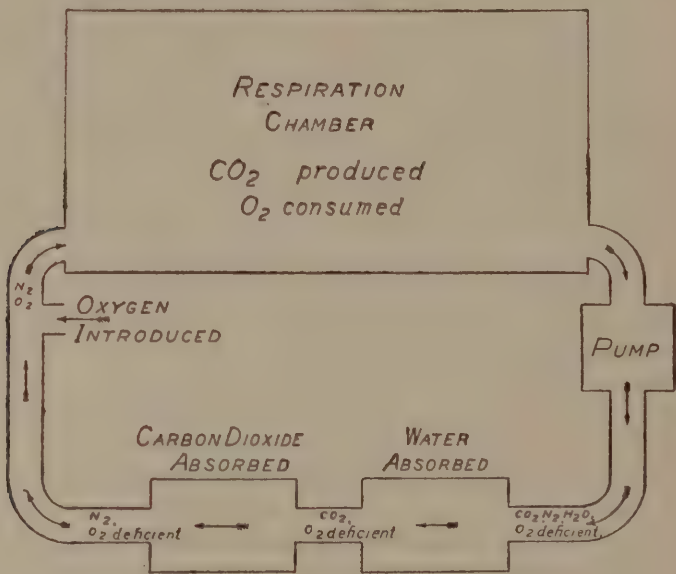

FIG. 1. Schematic outline of respiration apparatus.

The oxygen is determined directly by noting the amount it is necessary to introduce into the respiration chamber in order to secure the same volume of air in the chamber at the beginning and end of the experiment, making due allowance for changes in temperature, pressure, and water-vapor. While usually the amount of oxygen used is determined by allowing oxygen to flow into the respiration chamber from a previously weighed cylinder of the highly compressed gas and noting the loss in weight, it may likewise be accurately determined by passing the gas from a compressed cylinder through a carefully calibrated gas-meter which is submerged in water to prevent gross temperature fluctuations. The general plan of the apparatus is shown in the schematic outline given in figure 1.

As the infant gives off carbon dioxide and consumes oxygen, the air leaving the chamber is rich in carbon dioxide and water-vapor from the lungs and skin of the infant, contains a normal amount of nitrogen,

and is deficient in oxygen. By means of a rotary pump, the air is carried from the chamber and forced through sulphuric acid, which absorbs the water, then through soda lime to remove the carbon dioxide; oxygen is next introduced and when the air returns to the chamber it is free from carbon dioxide and water and contains a normal percentage of nitrogen and oxygen.

A somewhat more elaborate scheme of the respiration apparatus, giving in considerable detail some of the special connections, may be seen in figure 2. The chamber, *C*, in which the infant remains, with

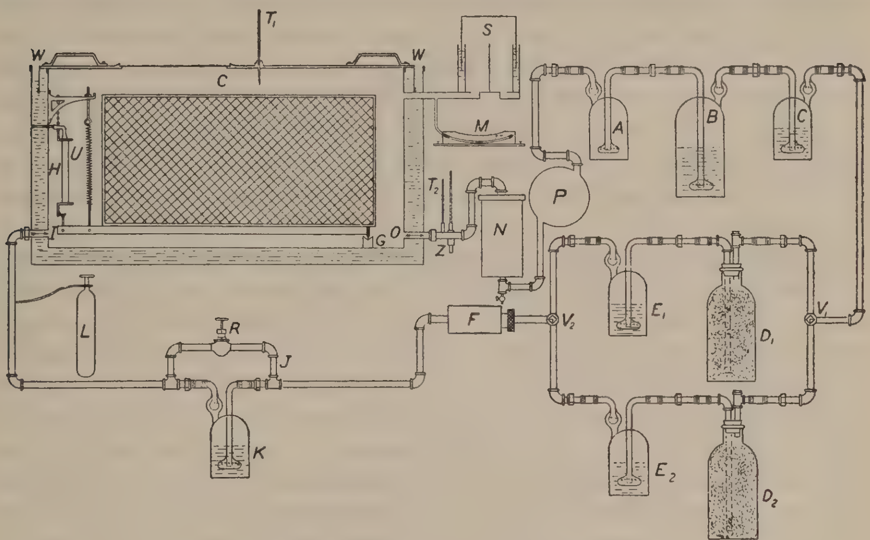

Fig. 2. Detailed scheme of respiration apparatus.

C, chamber; *W*, *W*, water jacket; *O*, outgoing air-pipe; *Z*, psychrometer; *N*, muffler; *P*, blower; *A*, acid trap; *B* and *C*, Williams water-absorbers; V_1 and V_2, 2-way valves; D_1 and D_2, carbon-dioxide absorbers; E_1 and E_2, air-dryers; *F*, sodium bicarbonate can; *J*, by-pass; *R*, valve; *K*, air moistener; *L*, oxygen cylinder; *I*, ingoing air-pipe; *S*, spirometer; T_1 and T_2, thermometers; *M*, manometer; *U*, spiral spring; *H*, pneumograph.

its surrounding water jacket, *W*, *W*, for temperature control, is shown at the upper left-hand corner of the figure. The air leaves the chamber near the right-hand end at *O*, and is drawn by the rotary pump over a wet- and dry-bulb psychrometer, *Z*, which gives the amount of moisture in the air of the chamber. A can, *N*, filled with dry cotton-batting is also placed in the air-current between the blower and the chamber to act as a muffler. After leaving the exhaust side of the blower, *P*, the air is forced through an empty glass bottle, *A*, which serves as a trap should any back pressure take place and sulphuric acid be forced back from the water-absorbing vessels *B* and *C*. These latter vessels, which are of peculiar construction, were designed by Dr. H. B. Williams, of the department of physiology of Columbia University, and will hereafter be designated as "Williams bottles." The air passes along a pipe

to a 2-way valve, V_1, where it may be deflected through either of the soda-lime bottles D_1 or D_2, in which the carbon dioxide is absorbed. Since the reagent must be somewhat moist to facilitate the absorption, it gives up water-vapor to the dry air-current, which must in turn be absorbed by sulphuric acid in the Williams bottles E_1 or E_2. The air next passes through the 2-way valve, V_2, and enters a small can, F, which contains dry sodium bicarbonate, the unweighable but noticeable sulphuric-acid odors being effectually removed by this means. The air then returns to the chamber through the by-pass J; or, if it is desired to moisten the air, the current can be deflected by closing the valve R in the by-pass J, so as to pass all of the air through distilled water in the Williams bottle, K. The air is now free from carbon dioxide and contains the water-vapor added in passing through K, but is still deficient in oxygen. This deficiency is made up by admitting oxygen from a cylinder, L, of compressed gas. The air thus enters the respiration chamber at I, somewhat moist and with approximately the normal percentage of oxygen.

Either series of absorbers may be used as desired, for if the air-current has been passing through the series D_1 and E_1 for a given experimental period, the air can be instantly deflected through the series D_2 and E_2, by turning simultaneously valves V_1 and V_2. As actually constructed, V_1 and V_2 are connected by a long rod, so that they may be thrown simultaneously by one movement of the hand.

Since the air-current is entirely closed, a small spirometer, S, is attached at the upper right-hand corner of the respiration chamber, thus providing for any expansion or contraction of the air. A thermometer, T_1, in the cover of the chamber, and a second thermometer, T_2, in the outgoing air, serve to indicate the temperature changes, while the manometer, M, shown below the spirometer, indicates the pressure of the air in the chamber.

By noting the increase in weight of the absorbers, D_1 and E_1 or D_2 and E_2, the amount of carbon dioxide absorbed is known. It is possible that the amount of water-vapor given up by D_1 to the dry air passing through it may be actually more than the amount of carbon dioxide absorbed, so that the bottle D_1 may lose in weight; on the contrary, the water-vapor given up is immediately absorbed by E_1, and hence the algebraic sum of the weight of the two bottles gives the weight of the carbon dioxide absorbed. Usually both bottles are weighed on a balance at the same time. The loss in weight of the cylinder L indicates the amount of oxygen absorbed, corrections being made for any variations in temperature and barometric pressure, or in the composition of the air inside the respiration chamber.

In figure 2 a general idea is given of the method of suspending the crib upon a stout spiral spring, U, at one end and a knife-edge, G, at the other. Alongside of the spring U is a pneumograph, H, the disten-

sion or contraction of which compresses the air inside of the pneumograph tube, thus transmitting, to a delicate tambour outside, a record of the slightest motion of the cage resulting from the movements of the infant. This method of obtaining a graphic record of the muscular activity is shown in more detail in figure 5 (p. 57).

While the general features of this apparatus have already been discussed in considerable detail,[1] with increased experience and with the facilities for modifying the technique to suit the conditions to be met, certain fundamentally important variations from the previously established technique have been found necessary. In this type of respiration apparatus the infant is lying in a crib inside of a small respiration chamber constructed of galvanized iron or copper and 77 cm. long, 25 cm. deep, and 37 cm. wide. To insure temperature control, the whole respiration chamber is surrounded by a water-jacket consisting of a second shell of galvanized iron or copper with a space of 5 cm. between the two shells. To withstand the pressure exerted by the weight of water, the two walls are separated by brass studs at approximately 5.5 cm. from each other, distributed all over the respiration chamber. This water jacket, which is filled with water to within a few centimeters of the top, acts also as a seal when the cover is placed upon the apparatus. Through this double-walled jacket pass the two pipes for the ventilating air-current, a pipe communicating with the spirometer or tension equalizer, a small pipe for the stethoscope tube, and a small pipe to connect the pneumograph of the body-movement registering device with the tambour outside. In the cover of the chamber are a window securely sealed and an opening for the air-thermometer.

In discussing the details of this apparatus, it seems best to follow in a general line the course of the ventilating air-current as shown in figure 2, from the time it leaves the respiration chamber until it returns. It should be stated at the outset that the general description of the apparatus previously referred to[1] gives a number of details that we can not enter into here, and that at this point we will discuss only such modifications as are essential for the successful prosecution of experiments with infants and small animals.

Psychrometer.—The psychrometer is essential for indicating the degree of moisture inside the respiration chamber. This is of value not only for the comfort or discomfort of the infant, but also for computing the amount of gas, particularly oxygen, inside the chamber at the end of the experimental period, since for these computations an exact knowledge of the water-vapor in the air is essential.

Formerly in the large respiration chambers it was necessary to aspirate a definite volume of air over pumice-stone drenched with sulphuric acid and note the increase in weight. Experiments carried out more

[1]Benedict, *loc. cit.*

recently have shown that in a specially constructed and very delicate psychrometer the depression of the wet-bulb thermometer can be measured with great accuracy and the amount of water-vapor in the air computed with an exactness sufficient for all practical purposes. The construction of this psychrometer, *Z*, is very simple. Two thermometers, each graduated in 0.1 degree and capable of being read with a lens to 0.01 degree, are placed in the air-circuit leading from the respiration chamber. The thermometer nearest to the chamber is the dry-bulb thermometer; around the bulb of the other thermometer is lightly attached a piece of fine linen which is continually kept moist with water drawn from a small reservoir by capillary attraction. By the use of the well-known psychrometric tables, it is possible to compute from the depression of the temperature the tension of the water-vapor, the degree of humidity, and the actual amount of moisture in the air. With the large respiration calorimeters, this has been carefully controlled both by the aspirator method—that is, by the aspiration of a certain volume of air over pumice-stone—and more particularly by the use of the extraordinarily ingenious and accurate psychrometer[1] of Dr. Klas Sondén of Stockholm.

The wet- and dry-bulb psychrometer as thus constructed gives most satisfactory results. It is, however, of the highest importance to make sure that the cloth around the wet-bulb thermometer is kept thoroughly drenched with distilled water, also that the capillarity of the fiber is good, as otherwise the cloth may become partially dried and inaccurate results obtained. Prior to each experiment, the wet bulb is drenched by using an elongated medicine dropper filled with distilled water.

Muffler.—Since a rotary pump is used to keep the current of air in motion, which rapidly draws in successive small portions of air, a puffing sound is produced which has proved somewhat disturbing to certain infants. To eliminate this, a small muffler, *N*, consisting of a brass can filled with cotton batting, is placed between the psychrometer and the blower.

Blower.—After experimenting with many different types of blowers, we have found the most satisfactory to be that furnished by the Crowell Manufacturing Company of Brooklyn, New York, under the specification No. O–D Rotary Compressor. This can be secured from the manufacturers in a surrounding iron box, which is suitable for an oil-immersion bath. It is a positive blower in that the air withdrawn from the chamber may be forced through a considerable number of layers of sulphuric acid and soda lime contained in suitable vessels. The blower (*P*) is connected by a leather belt to a small electric motor and can be provided with a safety clutch to prevent the reversing of the wheel through carelessness and the drawing over of sulphuric acid from the

[1]Sondén, Bihang till K. Svenska Vet.-Akad. Handlingar, 1891, **17**, p. 3; see also Meteorologische Zeitschr., 1892, p. 81.

water-absorbers. This latter feature has been found of advantage, although the insertion of the safety trap (*A*) has prevented this. The speed of the blower may easily be altered by a simple lamp resistance, these blowers usually giving a suitable ventilation—not far from 35 liters per minute—when rotating at the speed of 270 revolutions per minute. Even with this rate of ventilation, it has been shown by careful experimenting, with a portable alcohol lamp placed in different parts of the chamber, that there is no draft which would be noticed by the infant. The fact that the relative humidity does not become unduly low is further proof that the infant is sojourning in an atmosphere approximately normal.

Acid trap.—To prevent the possibility of sucking strong sulphuric acid into the delicate mechanism of the blower, an empty glass bottle (*A*) is inserted into the series. While almost any form of bottle can be used for this purpose, it has been convenient for us to employ an empty reversed "Williams bottle."

Water absorber.—The air leaving the respiration chamber contains a large amount of water-vapor from the lungs and skin of the infant and from the moisture of the incoming ventilating air-current. Before the carbon dioxide produced by the infant is absorbed, it is important to remove this water-vapor entirely from the air. The current is therefore first passed through two or more bottles containing concentrated sulphuric acid. Usually one large-sized Williams bottle (*B*) is sufficient to collect nearly all of the moisture, but this is followed by a second bottle (*C*), which retains the last traces of water-vapor.[1] To facilitate the handling of the bottles and to prevent breakage, they are usually inclosed in a small wire basket with a handle, by means of which they may be suspended directly from a hook on the arm of the balance. When these two Williams bottles are used, it is possible to retain the first bottle in the circuit until the acid has so far accumulated as to render it liable to be carried over mechanically into the second bottle. Indeed, 100 or 200 grams of water-vapor may be absorbed; it is fundamentally important, however, to note that the second Williams bottle must not increase in weight more than 15 grams before being renewed. As a matter of experimental routine, it has been found advantageous to replace the first Williams bottle each day with another which has previously served in the quantitative absorption of carbon dioxide, replacing these bottles with new ones every other day. The second Williams bottle should be controlled by weighing every few days.

Tubing and piping.—The Williams bottles, as well as the soda-lime bottles for absorbing the carbon dioxide, are fitted with short lengths of rubber tubing of good quality, to which are attached respectively male and female parts of ordinary garden hose couplings of the standard

[1]The Williams bottles are made for us in Berlin by the Vereinigte Fabriken f. Laboratoriumsbedarf.

$\frac{3}{4}$-inch size (approximately 16 mm. internal diameter). The couplings are therefore interchangeable with different forms of apparatus. With a standard rubber hose gasket, the couplings can be made air-tight by a simple twist of the hand. All of the piping throughout the apparatus is of standard $\frac{1}{2}$-inch (16 mm. internal diameter) galvanized iron pipe.

Two-way valve.—In order to deflect the main air-current from one set of purifiers to the other, it is necessary to have a 2-way valve, but unfortunately this can not be purchased in the open market. For this purpose we have taken an ordinary 3-way $\frac{1}{2}$-inch gas cock and soldered up one of the ports, then ground it again to fit the valve body. When properly done and the valve lubricated with a little cerate or vaseline, the result is very satisfactory. The valves V_1 and V_2 are of this type. A long steel rod connects these two valves so that by throwing the handle at one valve both valves are simultaneously closed and the air-current instantly deflected from one set of purifiers to the other.

Soda lime and containers.—The most effective absorbent for carbon dioxide that we have found is slightly moist soda lime. So important is the preparation of this reagent that we consider it fitting to republish the method here.

The soda lime is prepared in a round-bottom iron kettle, holding about 3 liters. For this purpose 1,000 grams of commercial caustic soda of good quality are dissolved in approximately 600 c.c. of water. When completely dissolved, 1,000 grams of finely pulverized quicklime are rapidly stirred into the hot lye and the stirring continued with a long-handled iron rod. The lime is immediately slaked, a large amount of heat and steam being given off. If the operation is carried on out of doors or under a good hood, soda lime may be readily made by unskilled labor.

For infants and for animals weighing not less than 3 to 5 kilograms the ordinary soda-lime containers are used (D_1 and D_2), these being wide-mouthed glass reagent bottles of the usual type. Each bottle contains 2 kilograms of soda lime, capable of absorbing not less than 75 grams of carbon dioxide, and weighs when filled about 4 kilograms. The moisture in the soda lime is essential to its efficiency, but the air after passing through the absorbent must again be dried by passing it through the Williams bottles E_1 or E_2.

Sodium-bicarbonate can.—In order to absorb the traces of acid fumes which may remain in the air after it has been carried through the Williams bottles, it is necessary to insert in the air-circuit a small can filled with dry sodium bicarbonate (F). This completely removes the acid fumes and does not affect the determination of the carbon dioxide or of the oxygen in any way.

Air-moistener.—With very small infants and with a fairly rapid flow of air, it is quite possible that the humidity inside the chamber may be too low for comfort and hence it is advisable to secure some means for

rapidly and accurately moistening the air to a suitable degree. For this purpose a Williams bottle (K), containing pure distilled water, is placed in the circuit in such a manner that, by closing a valve in the by-pass, the entire air-current may be forced through the water in this bottle or as little thereof as may be desired.

Oxygen.—The direct determination of oxygen may be made either by weighing a small cylinder of gas (L) and noting the loss in weight during the experiment or by using an exceedingly delicate and accurate gas meter. Small cylinders of compressed oxygen which can readily be weighed may be secured from the Linde Air Products Company of Buffalo, New York. These cylinders weigh when filled about 3 kilograms and contain about 150 grams of oxygen with a purity of about 97 per cent. The oxygen supplied by this company is made from liquid air and consequently the residual gas, instead of being nitrogen, as has commonly been supposed, is as a matter of fact in large part argon,[1] so that to the volume of oxygen measured, about 1 per cent should be added for the argon.[2]

One of the greatest difficulties in using these cylinders has been the selection of a suitable valve, that furnished on the cylinder by the manufacturer being difficult to utilize owing to the high pressure under which these cylinders are filled. Formerly recourse was had to one of the numerous types of reduction valves, but a thorough test of these did not result in securing such a valve as would functionate properly for any long period of time. One or two types of needle valves have been found which are much less expensive and give a satisfactory closure. Such a needle valve is coupled to the exit of the cylinder, then closed, and the main valve on the cylinder is opened to its fullest extent. The issuing gas may then be very delicately regulated by means of the needle valve. With so high a pressure it is obvious that the packing around the main valve stem should be excellent, so as to give no opportunity for leakage of air. The valves may be tested by immersing the cylinder and valve under water or by weighing the cylinder carefully on a balance and then again an hour later, when any loss of oxygen will be instantly apparent.

Gas meter.—From many standpoints the use of a small weighable cylinder of oxygen is to be recommended. On the other hand there are certain advantages in favor of using an accurately calibrated gas-meter under such conditions as to preclude excessive temperature fluctuations. In our experiments with infants we have almost always employed a large cylinder of oxygen with a valve, conducting the gas through a carefully calibrated meter of the type devised by Bohr and manufactured by the Dansk Maalerfabrik of Copenhagen. This gas meter registers one liter for each complete revolution of the drum. Being

[1] Claude, Comptes rendus, 1909, **151**, p. 752; Morey, Journ. Am. Chem. Soc., 1912, **34**, p. 491.
[2] For a discussion of this point, see Carnegie Inst. Wash. Pub. No. 187, 1913, p. 74.

constructed of britannia, it may without injury be completely immersed in water in a large aquarium vessel and so leveled as to be easily read. The corrections for temperature changes are minimized by this immersion in water. It is not possible, of course, to control the barometric fluctuations, and the meter readings should therefore be corrected not only for the average of the temperature fluctuations obtaining throughout the experimental period, but also for the average changes in the barometer. For relatively short periods this can best be done by using the temperature readings taken at the beginning and end of the period, and the barometer readings taken at the same time.

The meter is calibrated by the method of weighing the gas delivered from an oxygen cylinder.[1] Many tests of this type of meter show that, when properly installed, it gives admirable results and when a long series of experiments is contemplated, its use is strongly to be recommended. A small, weighable cylinder of oxygen is required in either method, since such a cylinder is necessary for the calibration of the gas meter.

Temperature measurements.—In the dog apparatus, the volume of air inside the respiration chamber is about 250 liters; in the infant apparatus it is about 75 liters. It is clear, therefore, that correct temperature measurements of this air are necessary in order to determine the actual volume of the air in the chamber at the end of every experimental period. We have thus far employed two carefully calibrated mercury thermometers to measure the average temperature of the air in the chamber, one in the cover of the chamber (T_1), the other the dry-bulb thermometer of the psychrometer (T_2). While the two thermometers rarely read alike, their fluctuations in temperature are usually parallel; consequently, for lack of better measurement, the average of the readings of the two thermometers is taken as representing the average temperature of the air in the chamber. Experiments are now in progress seeking a better record of the average temperature of the air by means of electrical-resistance thermometers.

Temperature control of the respiration chamber.—The importance of temperature measurement has just been outlined, but it is likewise important to conduct the experiments so that the respiration chamber shall not be subjected to sharp and sudden fluctuations of temperature during the experimental period. It has therefore been found necessary to construct the water-jacket entirely around the chamber, except on the top. The space between the two metal walls is filled with water. During cold weather, with a mercury thermo-regulator and a small burner beneath, temperature control can be very readily secured. In the excessively warm days of summer, when the temperature of the laboratory is considerably higher than that of the chamber, it is necessary to place ice in the water-tank. The ice floating on the water melts

[1]Benedict, Physical Review, 1906, **22**, p. 294.

and the cold current of water descends, thus tending to equalize the temperature of the whole system. By judicious use of ice, a reasonably good control of the temperature can be obtained, even in the warmest weather.

Spirometer or tension equalizer.—Although an absolute temperature control is theoretically possible with this apparatus, thus securing a constancy in the apparent volume of the air in the closed system, it is practically impossible to prevent slight temperature fluctuations, and these, together with the unavoidable and uncontrollable fluctuations in barometric pressure, demonstrate the necessity for some form of tension equalizer which will insure atmospheric pressure in the chamber. For this purpose a small spirometer (*S*) is used. The spirometer regularly attached to the "universal" respiration apparatus is provided with sundry devices for graphically tracing the volume of each respiration and indicating the total ventilation of the lungs when employed with adults. When the infant or dog respiration chamber is employed, the spirometer is used solely as a tension equalizer and accordingly, in figure 3, only those parts are shown which are essential to its use under such conditions.

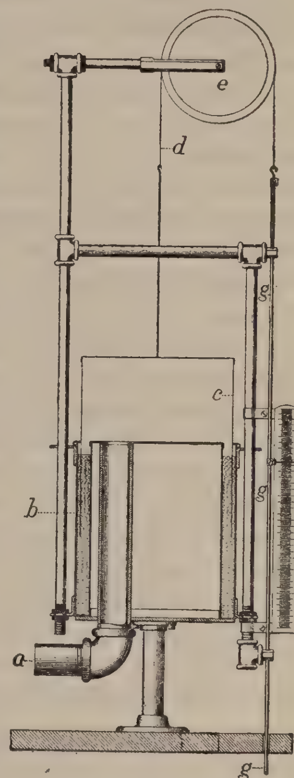

FIG. 3. Spirometer.

c, bell of spirometer; *d*, suspension cord; *e*, pulley; *g*, *g*, *g*, counterpoise; *b*, water or oil bath; *a*, air-pipe connecting with the respiration apparatus.

The upper part of this spirometer consists of a bell, *c*, constructed of very light copper or aluminium, suspended by a delicate cord, *d*, over a pulley, *e*, and counterpoised by a brass rod, *g*, *g*, *g*. This bell dips into a bath of water or oil in the annular space, *b*, between the two walls of the lower part of the spirometer. The pipe, *a*, connects directly with the respiration apparatus. By noting the position of the pointer on the millimeter scale at the right, the exact height of the bell can be seen at any moment. There is no particular compensation device used in connection with this spirometer to allow for the variations of the metal displaced as the bell enters or leaves the liquid; consequently there are, theoretically at least, slight alterations in the tension with the different positions so that it is advantageous to have the bell in nearly the same position at the beginning and end of each experimental period. It is our practice at the beginning of an experiment, after taking an initial reading of the height of the bell, to introduce a volume of oxygen approximately that which it is assumed that the infant will

use during the period. The oxygen supply is then shut off and the bell gradually sinks. It is highly desirable that at the end of each period the bell should always be sinking, thus in part compensating for the slight alteration in tension. More recently we have found it advantageous to move the counterpoise rod, *g*, *g*, *g*, up or down by hand at the exact end of the period until the very delicate petroleum manometer indicates that there is no pressure. At this point the reading is taken.

Manometer.—The small oxygen consumption and the large volume of the respiration chamber with its accessory parts make the influence of slight changes in temperature and pressure of great moment in measuring the total oxygen consumption. Consequently it is essential to note the exact pressure inside the chamber. This is assumed to be atmospheric, but it is possible that the spirometer does not respond instantly to slight changes in pressure; accordingly it is more efficacious to use a very delicate manometer. This manometer (*M*) is of the type employed by Pettersson and Sondén in their gas-analysis apparatus and indicates the slightest alteration in atmospheric pressure. It consists of a glass tube bent in the form of an arc and containing a few drops of petroleum oil.

Balance.—The soda-lime bottles weigh, together with the Williams bottles, approximately 6 kilograms. The necessity for determining the amount of carbon dioxide produced in a half-hour period to within 0.01 gram makes it imperative to secure a balance with a large carrying capacity and extreme sensitiveness. Such balances we have as yet been able to obtain from only one manufacturer.[1] Fortunately they are quite inexpensive. These balances—of which there are many sizes, all of which have been tested in this laboratory—give very accurate results, for with a load of 10 kilograms 1 centigram is easily recorded. The balances are substantially mounted and surrounded by a glass case for protection against any disturbing drafts.

METHODS OF TESTING THE RESPIRATION APPARATUS.

The respiration apparatus just described, though extremely simple in principle, nevertheless has certain complexities. For experiments with infants, therefore, it is necessary to test completely the feasibility of the apparatus for measuring or indicating the several factors. For this purpose it is of prime importance to know that the apparatus is absolutely air-tight, so that when the cover is properly in place, no air can enter or leave the circulating air-current. Fortunately this is very readily tested in this type of apparatus.

TESTS FOR TIGHTNESS.

By a consideration of the diagram given in figure 2, it will be seen that the entire ventilating current is a closed circuit, the tension equalizer or spirometer allowing it to expand or contract according to the

[1] A. Sauter, Ebingen, Württemberg, Germany. The specifications are as follows: No. 7 II*a*, with aluminium beam and iron support, black enameled, in glass case, with carrying power 10 kilograms.

variations in temperature, pressure, or actual volume of air inside the system. By reading the millimeter scale over which the pointer from the counterweight of the spirometer bell passes, it can easily be seen whether or not the apparent volume of air in the chamber is altered during a test.

To make such a test, all of the various parts of the apparatus are connected as in an experiment with an infant, and the ventilating air-current started. After the first moment or two, during which the air throughout the whole system will be attaining equilibrium, the bell on the spirometer should reach a constant level, and thereafter the air should remain absolutely constant unless affected by changes in temperature or atmospheric pressure, these being indicated by the readings of the barometer and the two air thermometers. If the changes in the position of the spirometer bell can not be accounted for by temperature or barometer changes, there is obviously a leakage of air into or out of the system, usually the latter.

To test the efficiency of the apparatus and the absence of a defect in any individual part, especially when assembling the parts or when trying to locate a leak, a water manometer, consisting of two glass tubes connected at the bottom by a short bit of rubber tubing and attached to a suitable standard, is found advantageous, inasmuch as the slightest leak in any individual portion of the apparatus can readily be detected by applying pressure with a bicycle pump. When the apparatus has been properly installed, with accurately fitting rubber gaskets and connections, and suitable inspection given from time to time, there is no occasion for leakage, so that such an occurrence can invariably be ascribed to faulty technique. Since the experiments with infants instantly follow the test of the apparatus, the only disturbance thereafter being the removal of the cover which fits into the water seal, it will be seen that these tests should prove an admirable index of the condition of the apparatus during the experimental period.

Tests for the efficiency of the absorbing vessels.—The amount of carbon dioxide given out by the infant is determined by noting the increase in weight of the soda-lime vessel (D_1 or D_2) with its attendant Williams bottle (E_1 or E_2); the degree of absolute moisture in the air when it enters the soda-lime bottle and leaves the Williams bottle should be identical. If, however, the sulphuric acid in the Williams bottle, E_1 or E_2, following the soda-lime container, is allowed to accumulate water to such an extent that its efficiency as a water-absorber is somewhat less than that of the Williams bottle, C, preceding the soda-lime container, it is obvious that there would be a loss of water from the system as a whole and the amount of carbon dioxide thus measured would actually be too small. Conversely, if the air is not as dry before it enters the soda-lime bottle as when it leaves the Williams bottle following, there will be an undue increase in the weight of the carbon-

dioxide absorbing system owing to the excess water absorbed. If the routine with the Williams and the soda-lime bottles is carried out as previously outlined, no difficulty is experienced, but it is advantageous occasionally to test the efficiency of the apparatus for absorbing carbon dioxide and water-vapor. Consequently, in testing for leaks it is advisable to weigh the sulphuric-acid and soda-lime vessels separately, and continue passing the air through the system for a half hour. Under these conditions, the loss in weight of the soda-lime vessel should of course be exactly counterbalanced by the increase in weight of the accompanying Williams bottle. With all of the experiments with infants here reported, this procedure was followed out every morning. It is needless to say that such precautions are no longer necessary, but inasmuch as this was the first year that the apparatus was used in the present form we considered it advisable to obtain this control before each experiment.

ALCOHOL CHECK TESTS.

The large respiration calorimeters in this laboratory have all been controlled by alcohol check tests as to their capability for measuring the carbon dioxide and the water-vapor produced, oxygen absorbed, and heat eliminated by the subject inside the chamber; we therefore hoped to secure as satisfactory control tests for this small respiration apparatus when used for infants. One of the greatest difficulties which immediately presented itself was that of developing inside the respiration chamber a known amount of carbon dioxide and absorbing a known amount of oxygen. A simple method for this would have been to place inside the respiration chamber an alcohol lamp and let it burn for several hours, noting the loss in weight of the lamp. It should be observed, however, that this respiration chamber is used for the most part during experiments with half-hour periods. We considered it unfair, therefore, to make an alcohol check experiment covering several hours and assume that the results showed that the apparatus would be equally as satisfactory for half-hour periods. The same problem arose in connection with the development of our first respiration apparatus for man,[1] and the difficulty was then overcome by burning a known amount of ether vapor. By reference to this earlier test, it will be seen that the special form of combustion chamber then used was perfectly comparable with the respiration chamber employed for infants. But the difficulties incidental to cooling the intense ether flame and making all the connections satisfactory rendered it practically impossible for us to carry out these tests in the hospital.

For many years an attempt has been made to secure some method for obtaining the actual amount of alcohol burned in a small lamp inside the respiration chamber in periods as short as 30 minutes. In lieu of

[1]Benedict, Am. Journ. Physiol., 1909, **24**, p. 372.

this ideal test, we had to content ourselves with alcohol check tests of the following character:

A small lamp, which was constructed from a 100 c.c. Erlenmeyer flask and partially filled with alcohol, was ignited and placed inside the respiration chamber. After a preliminary period of several minutes the air-current was deflected to the second set of purifiers, the proper readings taken, and several periods of 30 to 45 minutes each were carried out. Irrespective of the absolute amount of carbon dioxide absorbed by the soda lime or the total amount of oxygen admitted from the cylinder or measured by a meter, the relation between these two should be that obtaining in the perfect combustion of alcohol by oxygen. The respiratory quotient of alcohol, which can readily be computed, is found to be 0.666. Consequently the relationship between the amount of carbon dioxide absorbed and the amount of oxygen delivered through the meter or from the weighed cylinder was determined and if this was found to be approximately 0.666, it was assumed that the apparatus was functionating perfectly. As a matter of fact, such an alcohol check test was made usually once a week throughout the whole experimental year with values varying but little from the theoretical amount.

Deferring for the moment the description of the method of calculation, we give in table 16 the respiratory quotient for every alcohol check test carried out with this apparatus, the results being, for the most part, within the limits of experimental error.

TABLE 16.—*Respiratory quotients obtained in alcohol check experiments with the respiration apparatus for infants.*

Date.	Quotient.	Date.	Quotient.	Date.	Quotient.
1913.		1913.		1913.	
Jan. 9...	0.67	Apr. 10...	0.68	June 24...	0.68
15...	.68	17...	.67	25...	.66
16...	.68	29...	.67	Sept. 27...	.67
28...	.66	May 9...	.67	30...	.66
29...	.67	15...	.68	Oct. 4...	.66
Feb. 25...	.66	17...	.65	7...	.67
Mar. 1...	.68	23...	.66	9...	.66
14...	.69	June 5...	.66	9...	.67
21...	.68	14...	.70	Dec. 11...	.66
28...	.67	18...	.71	1914.	
Apr. 4...	.65	19...	.69	Jan. 1...	.65
				13...	.66

COMPLETE SHORT-PERIOD ALCOHOL CHECK TESTS.

Although the observations on infants reported in this publication were based upon the accuracy of alcohol check tests involving only the determination of the respiratory quotient, it is desirable to record at this point the development of a method which provided for the testing

of this identical apparatus and the proof of its accuracy for measuring the results of half-hour periods after an amount of carbon dioxide had been developed approximately equal to that produced by an infant. From the experience with the large respiration chambers in the Nutrition Laboratory, it became increasingly evident that the discrepancies shown in the alcohol check tests for short periods were to be ascribed not to errors in the absorption of carbon dioxide or to the calculation of the amount of oxygen produced, but to discrepancies in the measurement of the small quantities of alcohol necessary for the control test. The alcohol required for producing (when burned inside the respiration chamber) an amount of carbon dioxide equivalent to that given off by a small infant corresponds to about 1.00 or 1.50 grams per half hour. To measure this with an accuracy of 1 per cent and to insure that the measurement represents not only the amount of alcohol introduced but the actual amount consumed, involves much experimental work. Mr. T. M. Carpenter, of the Laboratory staff, has recently conducted experiments in which this second difficulty has been overcome.

In these experiments a small piece of capillary copper tubing was carried through the walls of the respiration chamber by means of the tube commonly used for the stethoscope, and then bent upward to form a minute lamp. The exterior end of the copper tube was connected by capillary rubber tubing to a glass burette of very fine caliber which could easily be read to 0.01 c.c. The burette and the capillary rubber tubing were suspended by a cord running over a pulley, so that both the burette and the rubber tubing hung free in the air. When this burette was very slowly and gradually raised, alcohol flowed with great regularity through the copper tube into the chamber, where it burned quietly. By reading the level of the alcohol in the burette at the beginning and the end of any given experimental period, the absolute amount of alcohol introduced could be accurately determined. A small wooden pulley attached to the vertical upright of a Porter kymograph was used for raising the burette regularly. An extremely even elevation of the burette could be secured by adjusting the speed of the rotating fan so that the amount of alcohol introduced per half hour ranged not far from 1.00 to 1.25 grams. The whole apparatus is shown in figure 4, in which may be seen the copper tube extending through the two walls of the respiration chamber, the flexible rubber tubing, one end of which is attached to the copper tube and the other to the burette, and the wooden pulley and kymograph in position to raise the burette as desired.

When beginning the experiment, the lamp was lighted, the kymograph set in motion, and after the lamp had burned a few moments and regularity of combustion was assured, the cover was put in place. At the end of a preliminary period of not far from 15 to 20 minutes, the

level of the alcohol in the burette was accurately read and the experiment proper began. Thereafter it was only necessary to read this burette accurately with a lens at the end of each experimental period of 30 to 40 minutes.

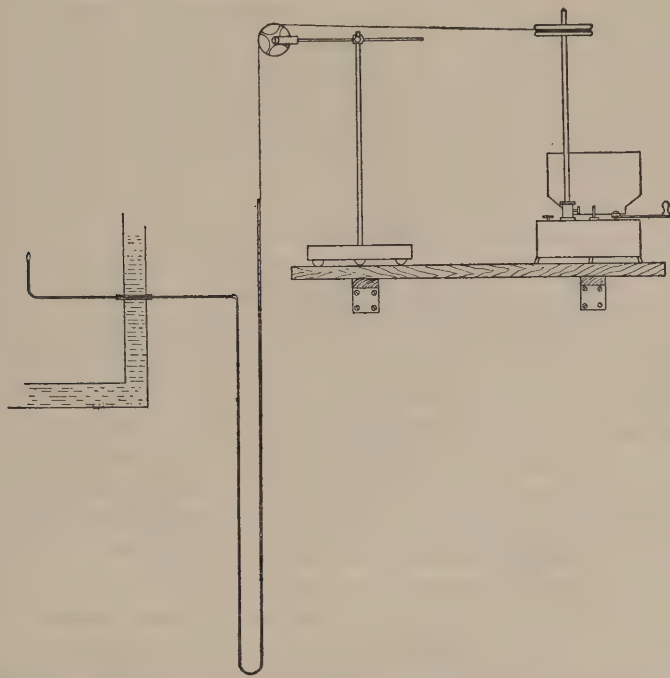

FIG. 4. Method of introducing alcohol in the alcohol check tests of respiration apparatus.

The ventilating air-current was passed through the chamber at the rate of approximately 35 liters per minute, and with a flame of this size and regularity in the introduction of alcohol the amount of carbon dioxide residual in the chamber at the end of each experimental period was usually very constant. Since, however, we were dealing with quantities of carbon dioxide amounting to 0.01 gram, it was necessary in this exceedingly exact work to determine the residual amount of carbon dioxide. This was obtained by drawing a sample of the air at the end of each period, and determining the amount of carbon dioxide by means of a modified[1] Pettersson-Palmquist gas-analysis apparatus, which permits measurements of 0.5 or less per cent of carbon dioxide to the third significant figure. Its manipulation is very simple and has been rapidly acquired by a number of workers in the laboratory. It should be stated that these residual analyses were not required in the observations on infants at the hospital, but were necessary only to secure the greatest degree of refinement in establishing the accuracy of

[1]Anderson, Journ. Am. Chem. Soc., 1913, **35**, p. 162.

the apparatus for measuring minute quantities of carbon dioxide and oxygen.

Method of computing the carbon-dioxide production.—In these alcohol check experiments, the carbon-dioxide production is found by weighing the soda-lime container with its accompanying Williams bottle, the increase in weight giving the amount of carbon dioxide produced during the period, assuming no change in the amount of carbon dioxide residual in the chamber. If extreme accuracy is desired, determinations of the residual amount of this gas are made as outlined above and any variations corrected for.

Method of computing the oxygen consumption.—The computation of the oxygen consumption is much more elaborate than that of the carbon-dioxide production, for while a rough measurement of the total oxygen consumption can readily be obtained by noting the loss in weight of the cylinder of gas or by reading directly the volume of gas passing through the Bohr meter, there are nevertheless a number of factors which affect these determinations, all of which must be taken into consideration. For example, the spirometer bell is at a certain height at the beginning of an experiment; if at the end this bell is either above or below this point, a correction therefor must be applied. If above, an excessive amount of oxygen has been added, and if below, the amount of oxygen is deficient. As each millimeter difference in the height of the spirometer bell corresponds to 23 c.c. of gas, the computation is very simple. On the other hand, if there is an increase in the temperature inside the chamber, the air expands and even if the spirometer bell is in the same position at the end of the period as at the beginning, less oxygen has evidently been introduced than if the temperature had remained constant. Conversely, if the temperature has fallen, more oxygen has been introduced. Similarly, if the barometric pressure has altered materially, it has likewise affected the introduction of the oxygen. For an exact computation of the amount of oxygen consumed by the subject, therefore, not only is it necessary to know the amount introduced from the weighed cylinder or through the Bohr meter, making due corrections on the readings of the gas meter for the factors of temperature and pressure and the mechanical factor of the meter itself, but likewise a correction for the alterations in the total volume of air inside the ventilating air system should also be made, since any alteration of the volume of the air inside the system represents a corresponding error in the oxygen introduced. For this purpose, it is necessary to note, first, the volume of air inside the chamber, which is roughly found by a simple computation; second, the temperature of the air in the chamber as shown by the readings of the two thermometers; third, the barometric pressure; fourth, the degree of humidity as obtained from the wet- and dry-bulb psychrometer, since the water-vapor in the chamber may also vary; and fifth, in exceed-

ingly refined experimenting, the amount of carbon dioxide present in the residual air. The protocol of a single alcohol check test by this later quantitative method may serve to illustrate simultaneously the method of calculation and the accuracy of the apparatus.

DETAILS OF TYPICAL QUANTITATIVE ALCOHOL CHECK TEST.

Measurement of the residual carbon dioxide and oxygen.—This experiment consisted of two periods, the first from $11^h\ 30^m$ a. m. to $12^h\ 11^m$ p. m., and the second from $12^h\ 11^m$ p. m. to $12^h\ 51^m$ p. m. At the beginning and end of each period of the experiment, observations were made of the humidity conditions, the temperature of the apparatus, and the barometric pressure. By means of these observations and the determination of the carbon-dioxide content of the air in the chamber, the volumes of oxygen and nitrogen and of the carbon dioxide residual in the apparatus were obtained for the standard conditions of 0° C. and 760 mm. pressure. The observations made at the end of the first period are given in table 17.

TABLE 17.—*Observations at end of first period of alcohol experiment of October 9, 1913.*

Psychrometer: Dry bulb (t_1) 19.80° C.; wet bulb (t_2) 15.91° C.
Temperature at top of chamber (t_3) 21.63° C.
Temperature of apparatus (t_4): t_1 = 19.80° C.; t_3 = 21.63° C.; average, (t_4) 20.72° C.

Barometer: Reading at end of period	767.05 mm.
Tension of aqueous vapor in chamber	11.10 mm.
Corrected barometer (p)	755.95 mm.

Residual carbon dioxide and oxygen:

			Logs.		
Total volume of apparatus	81.5 liters	=	91116		
Temperature of apparatus	$\frac{1}{1+0.00367\ t_4}$	=	96817		
Corrected pressure	$\frac{p}{760}$	=	99768		
Corrected volume $CO_2 + O_2 + N_2$		=	87701	=	75.34 liters.
Per cent CO_2 (by analysis) 0.098		=	99123		
Residual CO_2		=	86824	=	0.07 liter.
Residual $O_2 + N_2$					75.27 liters.

The temperature of the air in the chamber of the apparatus was not determined with absolute certainty. The thermometer placed in the top of the apparatus (t_3 in table 17) recorded temperatures which, because of the position of the lamp and the warm air rising to the bulb of the thermometer, were without doubt too high. The record obtained from the dry-bulb thermometer (t_1 of table 17) shows the temperature of the air immediately after it left the chamber. It is believed that the average of these two records (20.72° C. in table 17) gives an approximate value for the temperature of the air in the apparatus at the time the records were made and that the change in temperature from the beginning to the end of the period may by this means be obtained.

The barometer record in millimeters is also shown in table 17. From the psychrometer observations the humidity of the air within the apparatus is known. Deducting from the barometric pressure the tension of aqueous vapor (11.1 mm.) for this observed humidity, allowance is made for the volume of water-vapor present within the apparatus. The corrected barometer reading, p, is then used.

The total volume of the apparatus is 81.5 liters. In order to determine the total volume of water-free air under standard conditions of temperature and pressure, *i. e.*, 0° C. and 760 mm., to the logarithm of this total volume is added, first, a logarithmic factor for the average temperature recorded and, second, a logarithmic factor for the corrected pressure. These factors are obtained from tables which have been prepared for the purpose. The standard temperature reduction is represented by the formula $\frac{1}{1+at_4}$, t_4 representing the temperature of the apparatus. The reduction factor of pressure for standard conditions is obtained from the ratio $\frac{p}{760}$, in which p represents the corrected barometer. The total volume of oxygen and nitrogen is then obtained from the total volume of water-free air by deducting the volume of carbon dioxide as determined by the analysis with the Pettersson-Palmquist apparatus. No attempt is made to separate the volume of nitrogen, since the amount of this gas remains unchanged and the absolute amount of oxygen is not desired.

Measurement of the carbon dioxide absorbed and the oxygen admitted.—The records of the carbon-dioxide production and oxygen consumption for the first period of the experiment are given in table 18. The carbon

TABLE 18.—*Carbon dioxide absorbed, oxygen admitted, and alcohol burned in the first period of alcohol check experiment.*

Oxygen admitted.[1]	
Weights of oxygen cylinder:	
Start................	3408.41 gm.
End................	3405.00 gm.
O_2 =	3.41 gm.
Impurity correction.......	−.01 gm.
Spirometer correction......	−.03 gm.
Total O_2 =	3.37 gm.
Carbon dioxide absorbed.	
Weights of absorbers, G+44:	
End................	5125.90 gm.
Start................	5122.78 gm.
CO_2 =	3.12 gm.

Alcohol burned.
One gram 92.56 p. ct. absolute alcohol yields 1.769 gm. CO_2 and requires 1.930 gm. O_2.
Burette readings:
11^h 30^m a.m.... 0.590 c.c.
12 11 p.m.... 2.770 c.c.
Difference..... 2.180 c.c. at 21.05° C. = 2.169 c.c. at 15.6° C.
2.169 c.c. (sp. g. 0.81576) = 1.769 grams (C_2H_5OH).
1.769 × 1.769 = 3.13 gm. CO_2 produced.
1.769 × 1.930 = 3.41 gm. O_2 used.

[1] The calculations are here made on weight. For a method of determining the oxygen consumption by volume, see Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 181.

dioxide absorbed from the ventilating air-current was determined from the amount collected in the absorbing vessels, which were weighed at the beginning and end of each period. The amount of oxygen admitted to the apparatus was found from the change in weight of a cylinder of oxygen, which was also weighed at the beginning and end of each period, correction being made for the known impurities contained in the oxygen. Correction was also made for the change in volume of the spirometer, which, in the period represented by table 18, rose 1 mm. corresponding to 23 c.c. or 0.03 gram of oxygen. This, for convenience, is deducted from the corrected amount admitted from the cylinder.

Measurement of the alcohol burned and the calculation of the products of combustion.—The records of the alcohol burned and the calculation of the products of the combustion during the first period of the experiment are also given in table 18. The alcohol used in this experiment was 92.56 per cent ethyl hydroxide by weight, the combustion producing 1.769 grams of carbon dioxide for each gram of alcohol burned and requiring 1.930 grams of oxygen for the oxidation. The readings of the burette at the beginning and end of the period were respectively 0.590 c.c. and 2.770 c.c. at the average temperature of 21.05° C., or 2.169 c.c. at 15.6° C. The multiplication of this amount by the specific gravity at 15.6° C. (0.81576) gives 1.769 grams as the weight of alcohol burned. This amount, in turn multiplied by the factors 1.769 grams for carbon dioxide and 1.930 grams for the oxygen, gives respectively the theoretical amounts of carbon dioxide produced and oxygen consumed as a result of the combustion.

Comparison of the theoretical amounts of carbon dioxide produced and oxygen consumed with those measured by the apparatus.—The amounts of carbon dioxide produced and oxygen used as measured by the apparatus are found by correcting the amounts of carbon dioxide absorbed and the oxygen admitted for the change in the residual amounts present in the chamber. Comparison of the amounts found with the theoretical amounts as calculated from the weight of alcohol burned shows that for the entire experiment 98.7 per cent of the carbon dioxide produced was measured and 100 per cent of the oxygen used. The comparison is given in table 19.

As supplementary evidence on the alcohol check tests, measurements made in four other experiments with the baby respiration apparatus and one check test of two periods with another respiration apparatus of exactly the same type but used for dogs are presented in table 20. In considering the data for the experiment with the dog respiration apparatus, it should be stated that the volume of air in the chamber is over three times as large as the volume of air in the baby respiration apparatus; hence the errors incidental to accurate oxygen determinations are greatly magnified. In spite of this, however, it can be seen that the results for both forms of apparatus are very satisfactory, showing that

measurements having a high degree of accuracy may be secured with either.

At this point emphasis should be laid upon the necessity of selecting a chamber of suitable size for the animal or the individual to be studied. The chamber having the smallest inner dimensions compatible with the comfort of the subject is to be preferred.

TABLE 19.—*Summary of measurements in alcohol check test of October 9, 1913.*

Time.	Carbon dioxide.			Oxygen.			Respiratory quotient.	Carbon dioxide.	Oxygen.
	Residual in chamber.	Carbon dioxide produced.		Residual in chamber.[1]	Oxygen used.				
		Found.	Theory.		Found.	Theory.			
First period.	*gram.*	*grams.*	*grams.*	*liters.*	*grams.*	*grams.*		*p. ct.*	*p. ct.*
$11^h\ 30^m$ a.m.	0.20	....	....	75.30	....	....	....	....	.....
$11^h\ 30^m$ a.m. to $12^h\ 11^m$ p.m.	.15	3.07	3.13	75.27	3.41	3.41	0.65	98.1	100.0
Second period. $12^h\ 11^m$ p.m. to $12^h\ 51^m$ p.m.	.20	2.96	2.98	75.18	3.25	3.25	.66	99.3	100.0
Total ...	....	6.03	6.11	.....	6.66	6.66	.66	98.7	100.0

[1]Residual oxygen + nitrogen.

TABLE 20.—*Summary of measurements in alcohol check tests of the baby respiration apparatus and the dog respiration apparatus.*

Date.	Apparatus and time.	Carbon dioxide produced.		Oxygen used.		Respiratory quotients.	Percentage found.	
		Found.	Theory.	Found.	Theory.		Carbon dioxide.	Oxygen.
		gm.	*gm.*	*gm.*	*gm.*			
1913. Sept. 30	Baby. $2^h\ 23^m$ p.m. to $2^h\ 53^m$ p.m.	2.20	2.22	2.44	2.42	0.655	99.1	100.8
	2 53 — 3 23	2.24	2.30	2.49	2.51	0.655	97.4	99.2
	3 23 — 3 49	1.88	1.93	2.05	2.10	0.655	97.4	97.6
Oct. 4	Baby. $12^h\ 49^m$ p.m. to $1^h\ 20^m$ p.m.	2.33	2.31	2.57	2.52	0.660	100.9	102.0
	1 20 — 1 52	2.15	2.19	2.39	2.39	0.655	98.2	100.0
Oct. 7	Baby. $1^h\ 42^m$ p.m. to $2^h\ 18^m$ p.m.	2.70	2.76	2.94	3.01	0.665	97.8	97.7
	2 18 — 2 54	2.66	2.69	2.87	2.93	0.670	98.9	98.0
Oct. 9	Baby. $3^h\ 18^m$ p.m. to $3^h\ 58^m$ p.m.	2.65	2.61	2.86	2.85	0.675	101.5	100.4
	3 58 — 4 38	2.58	2.64	2.82	2.88	0.665	97.7	97.9
Sept. 26	Dog. $8^h\ 53^m$ a.m. to $9^h\ 33^m$ a.m.	2.92	2.99	3.22	3.26	0.660	97.7	98.8
	9 33 — 10 13	2.79	2.83	3.06	3.09	0.665	98.6	99.0

METHOD OF DETERMINING THE DEGREE OF MUSCULAR REPOSE.

The intimate relationship between minor muscular activity and metabolism was soon recognized in experimenting with men in the large respiration calorimeter at Wesleyan University, Middletown, Connecticut, and all of the earlier publications of researches with this apparatus accentuate the importance of having a regular life routine throughout the experimental period. The first attempt to secure such regularity was the preparation of a program for each experiment, to be rigidly adhered to by the subject. This was followed by a record, made directly on the protocol sheets, of both the major and minor muscular movements which were noted by the physical observer through the window of the respiration calorimeter—a routine that was carried out for a number of years in all of the experiments.

In the later experiments made at the Nutrition Laboratory in Boston, a pneumograph was placed about the chest of the subject, primarily to record the respiration and the pulse-rate. These curves showed not only the rise and fall of the chest in respiration, but also any other muscular movements of the subject. This record was the first step towards a graphic representation of muscular activity during metabolism experiments, and played a very important part in an extensive research on diabetes[1] in comparing the metabolism of normal individuals and diabetics.

APPARATUS USED IN THE RESPIRATION EXPERIMENTS.

The success of this method of graphic registration in experiments on man led to the development of a method for the registration of the movements of animals. The first apparatus used in this laboratory was that devised by Benedict and Homans,[2] in which one end of the cage containing the animal was supported by a knife edge and the other by a stout spiral spring; the slightest change in the center of gravity of the animal changed the tension upon the spiral spring, causing the suspended end of the cage to move up or down. By means of a rod connected with the end of the cage and carried out through the top of the chamber, the movements of the cage were traced directly upon a kymograph. The mechanical difficulties of passing this rod through the cover of the chamber, which must be air-tight, were overcome, but later a tube pneumograph was substituted. This pneumograph was attached to the cage and the wall of the chamber parallel to the spiral supporting the free end of the cage. The slightest lengthening or shortening of the pneumograph produced a change in the tension of the confined air, these varying air tensions being transmitted by a tube through the walls of the chamber to a delicate tambour and pointer which gave graphic records on a kymograph drum.

[1]For a reproduction of these curves, see Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 136, 1910.

[2]Benedict and Homans, Am. Journ. Physiol., 1911, **28**, p. 29.

This method proved admirable for use with animals and was subsequently added by us to the respiration apparatus for infants. We have in an earlier publication pointed out the advantages of securing such records and have likewise given some characteristic tracings.[1]

The same principle has been applied to the bed calorimeter in use in the Nutrition Laboratory.[2] For this apparatus, however, we have recognized the fact that while infants when moving usually change the center of gravity lengthwise of the body, the muscular movements of adults are apt to be in a lateral rather than a longitudinal direction, so that the center of gravity is changed across the body. Accordingly the knife edges are placed on one side of the bed and spiral springs on the other when used for adults, rather than at the foot or head as when used with the crib or cage for infants or animals.

Certain details of the crib suspension have already been given in figure 2, but the exact connection between the crib and the tambour is shown in figure 5. One end of the crib, *L*, rests on a knife edge, *O*, while the other is supported by the spiral spring, *M*. A tube pneumograph, *N*, has its lower end attached to the crib, the upper end being fastened to a stout support soldered to the wall of the respiration chamber. The changes in tension of the air in the pneumograph are transmitted through the tube to a tambour, *P*, whose pointer traces the record upon the kymograph drum. A glass tee, *T*, with rubber tube and pinchcock, serves to equalize the tension in the tambour if there should be any permanent contraction or distention of the pneumograph.

The careful and frequent testing of both the pneumograph and the tambour for tightness is of practical importance. The pneumograph being inside the respiration chamber, and connected by a rubber tube to the outside, would obviously furnish a path for leakage of air out of the chamber, provided a leak in both the pneumograph and tambour should occur. Tests are readily made by immersing them in water and employing slight pressure with the mouth on the connecting rubber tube. The pneumograph is of the type regularly furnished by the Harvard Apparatus Company, but for use in the infant chamber it is somewhat shortened. The tambours, which are likewise supplied by the Harvard Apparatus Company, are covered with very delicate tambour rubber, which is liable to deterioration and should thus be frequently renewed and tested.

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[1]Benedict and Talbot, Am. Journ. Diseases of Children, 1912, **4**, p. 129.

[2]After the observations reported in this publication had been completed, information was received from Dr. Paul Roth, of Battle Creek, Michigan, that in recording the body movements of men or women lying on beds, he had replaced the pneumograph with a small Politzer bulb, so adjusted as to be somewhat compressed by the bed frame. The bulb was connected to the tambour and kymograph. Preliminary tests made in the Nutrition Laboratory with the Politzer bulb arrangement have shown that the results of the variation in pressure on the Politzer bulb by variation in muscular activity are most satisfactory, not only with adults but also with small animals—a fact of special interest in connection with the research on infants. Two serious objections to the pneumograph, *i. e.*, the danger of leaks through the rubber and the difficulty of renewing the rubber, are thus obviated by the use of this bulb. A flexible rubber bulb of small size is best used.

A major change in position of the body of infants during the respiration experiment is not ordinarily to be expected. With animals there may be a change in the center of gravity of the body from one part of the cage to the other, and consequently a distension or shortening of the pneumograph with a corresponding increased or decreased tension on the tambour. Under these conditions it has been found advan-

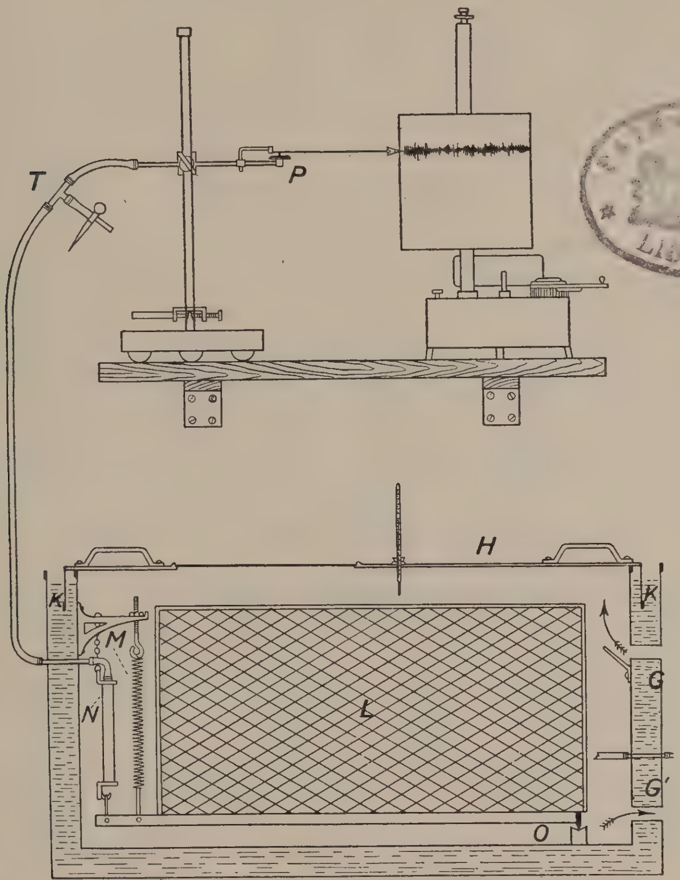

FIG. 5. Method of obtaining graphic record of muscular activity.

L, crib; *O*, knife-edge support; *M*, spiral spring; *N*, pneumograph; *P*, tambour; *T*, tee for equalizing tension; *H*, cover of apparatus; *K*, water bath; *G*, ingoing air-pipe; *G′*, outgoing air-pipe.

tageous to place in the rubber tube leading from the respiration chamber to the tambour a glass tee tube, with a short rubber tube and pinchcock on the open end. When the animal or infant has permanently or temporarily settled down in a new position and the tambour shows a distension or contraction, by opening the tee tube the normal pressure can again be secured and the curves will proceed at the normal level.

For the graphic record we have used extensively the simple Porter kymograph manufactured by the Harvard Apparatus Company, the most advantageous speed of rotation corresponding to one complete revolution of the drum in about 30 minutes.

It has been found desirable to precede the experiment with a test of the sensitivity of the apparatus for giving a good graphic record of the movements of the crib to make sure that the tambour rubber is intact and that there is a reasonably constant tension upon the tambour. For this purpose a weight is placed in the center of the crib approximately equivalent to the weight of the infant upon whom the observations are to be made. The tambour and pneumograph are then connected as usual and the kymograph set in motion, the speed being the same as that used in the experiment following. A 50-gram weight is next dropped from a definite height (21 cm.) so as to strike the crib a blow at a certain distance (32 cm.) from the knife-edge bearing upon which the crib rests. This imparts a slight impulse to the whole suspended system and a series of vibrations takes place. The amplitude of the vibrations as well as the number of the vibrations which continue after the first impulse indicate the sensitivity of the apparatus. This test is of great significance, accompanying as it does the kymograph record for each experiment and proving positively that the recording apparatus is in excellent condition. It also gives a rough estimate of the degree of muscular activity and the true value of the magnitude of the excursions of the pointer as the result of any restlessness on the part of the infant.

The tambour was usually adjusted in the observations with infants so that the distance between the end of the writing point and the center of the tambour rubber was 190 mm. and from the center of the tambour to the fulcrum 25 mm.; all of the magnifications were therefore on the same basis. The curves may be made to show motions that would otherwise be imperceptible to the eye by altering the magnitude of the multiplication and the sensitivity of the apparatus. For example, it has frequently been observed with both dogs and infants that when the animal or the infant is very quiet, even the slight change in the center of gravity produced by the respiratory movement has been sufficient to give a clear and regular record of the respiration-rate. Ordinarily such a degree of sensitivity is not at all necessary and is not regularly employed.

A typical kymograph curve, which was obtained with D. M. on March 26, 1913, is given in figure 6. This also shows a record of the sensitivity test which preceded the experimental periods. The vibrations of the crib after the weight had fallen are shown by typical curves which gradually decrease; the small disturbances of the line following, also resulting in curves, are due to the lifting of the weight. After the first test, the speed of the kymograph was increased and three tests were made at the higher rate of speed.

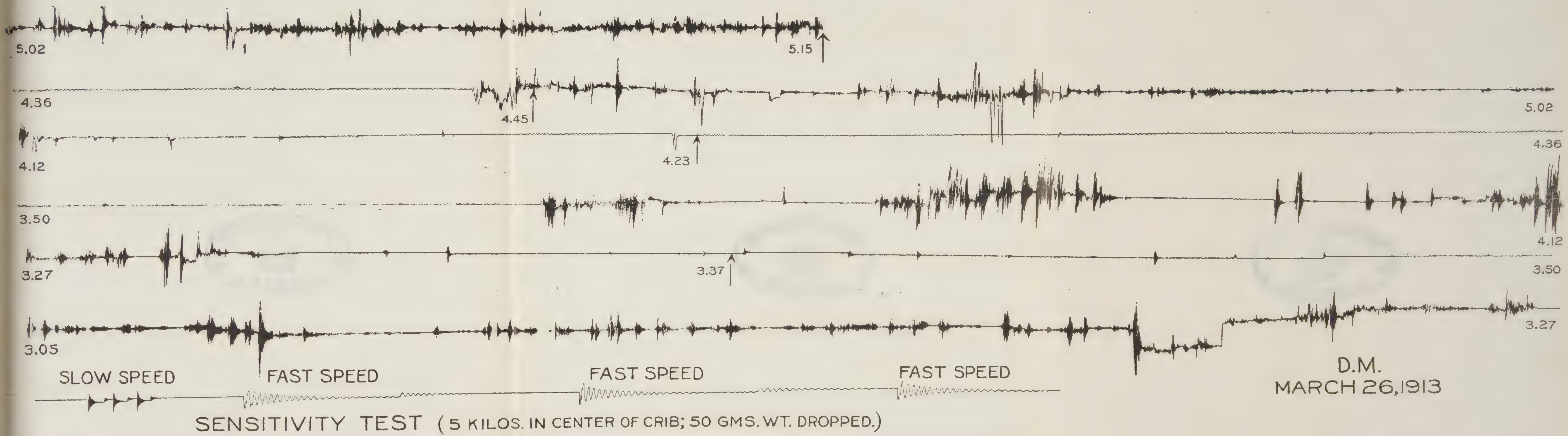

FIG. 6. *Typical kymograph curve, showing record of the muscular activity and the sensitivity test.*

The apparatus was so sensitive that even the slight movements due to respiration are clearly indicated, especially in the quiet period between 4^h 12^m p. m. and 4^h 45^m p. m. It will be seen by this curve that there were several major changes in the position of the infant's body which resulted in a total displacement of the level of the curve. Shortly afterward, air was released through the tee tube and the pointer was brought back to the original level. In any attempt to quantify the values of the different periods, these displacements of the curve due to major movements should be taken into consideration. A movement may not be sufficiently great to produce a considerable amplitude of the pointer and yet be produced by a shifting of the whole body, thus establishing a new, permanent center of gravity of the system. Obviously, in this case, a greater displacement could reasonably be supposed to have taken place than when the line returned to the same level.

It should be stated that the ocular method of observation of infants or animals during respiration experiments is most illusive and unsatisfactory. We have repeatedly seen experimental periods when a careful observer, even though watching the infant continuously, was unable to record a perceptible movement other than those of respiration, and yet the suspended crib, pneumograph, and tambour have recorded distinct and persistent muscular tremors, accompanied in all cases by an increasing pulse-rate and increased metabolism as measured by the oxygen consumption and the carbon-dioxide production. While, therefore, careful ocular observations, such as were made in the earlier experimenting at Wesleyan University in Middletown, Connecticut, are of great value in interpreting the gross metabolism, for extremely accurate observations the graphic method alone insures scientifically exact results. It is furthermore obvious that the sensitivity of the graphic method makes the continuous attention of an observer unnecessary, as the record of body movement is directly written without bringing the personal equation in any way into play.

WARD CRIB RECORDER.

The relationship observed between the graphic tracings of the muscular activity and the katabolism indicated the possible value of recording the activity of the infant throughout the day when it was not inside the respiration chamber. Accordingly, to assist in settling some complicated problems of nutrition, a special apparatus was devised and set up in the children's ward of the hospital in order to obtain a continuous graphic record of the muscular activity of the infant.

This apparatus, which was designated the "ward crib recorder," consisted of a small crib, one end of which rested on two hardened steel points and the other was suspended by a strong spiral spring. The movements of the crib due to the activity of the infant were graphically

recorded by means of a pneumograph, tambour, and kymograph as used for the same purpose with the respiration apparatus (see figure 7).

For these 24-hour observations, the kymograph was set at a very much slower speed than in the short-period observations with the respiration apparatus to avoid the necessity of changing the kymograph frequently. The curves were therefore not so sharply defined as those secured when the infant was in the respiration chamber. Numerous curves were obtained with the ward crib recorder during the winter of 1913. The kymograph was adjusted by the nurses in charge, oftentimes during the night, so that certain irregularities in the time record are to be expected. When the infant was removed from the crib for bathing, nursing, or any other cause, the kymograph was of course stopped and a break in the record occurred. Such records as these, which were frequently obtained with infants who were supposed to be lying quietly in the crib throughout the night, are particularly helpful in estimating the needs for energy.

More recently another form of this recorder has been devised and successfully used. In this later apparatus the adjustment of the crib by means of the spiral spring remains the same. Instead of using the pneumograph and rubber tambour, however, the measurements and manipulation are simplified by substituting an ordinary mechanical counter. This consists of a small revolution counter, such as a Veeder counter, to the axle of which is attached a thin aluminium wheel 119 mm. in diameter, with a milled edge. A lever and spring pawl are attached to this toothed wheel in such a way that each upward movement of the crib causes the wheel to move slightly in the direction of the hands of a clock. As the crib returns to its original position, any back movement of the wheel is prevented by a second pawl fastened to the base of the recording device, but the spring pawl which engages in the teeth of the wheel slides back to its original position without material resistance. Since every upward movement of the crib produces a rotary motion of the wheel, it will be seen that the total movement for any period can be obtained from the number of revolutions of the wheel as recorded by the counter. The wheel is divided into 10 equal divisions and provided with a pointer, so that the readings may be obtained in hundredths of a revolution if desired. The details of the later device are shown in figure 8.

Two curves obtained with this form of the ward crib recorder are given in figure 9, one of these being for a very restless infant, J. P., November 14–15, 1913, and the other for one much less restless, M. A., November 17–18, 1913. With the restless infant, the toothed wheel made 18.4 complete revolutions during the period from 6 p. m. to 7 a. m. In the curve obtained with the less restless infant, the wheel made 5.2 complete revolutions in approximately the same time, *i. e.*, from 5 p. m. to 7 a. m.

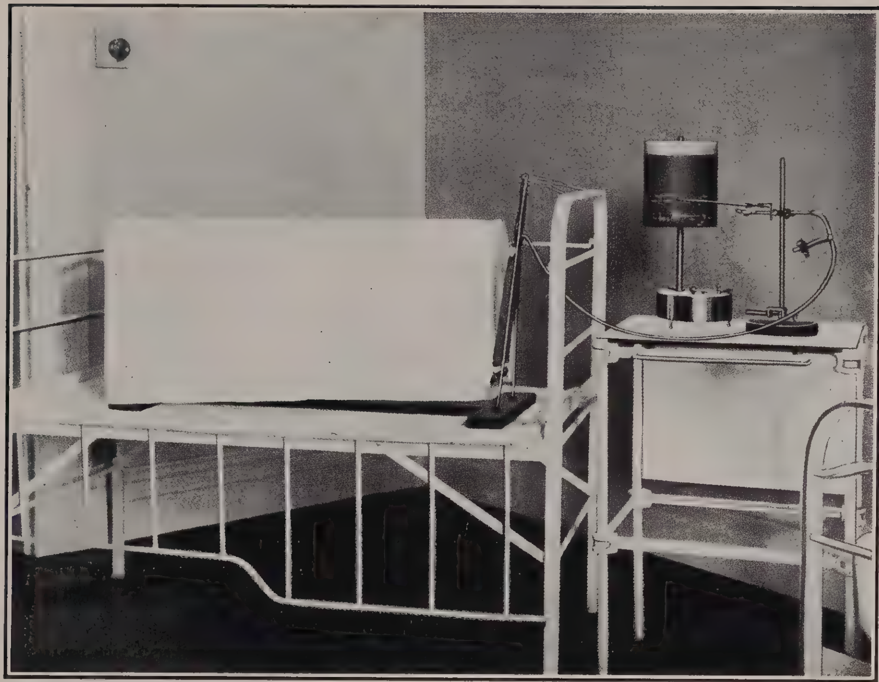

Fig. 7. Ward crib recorder.

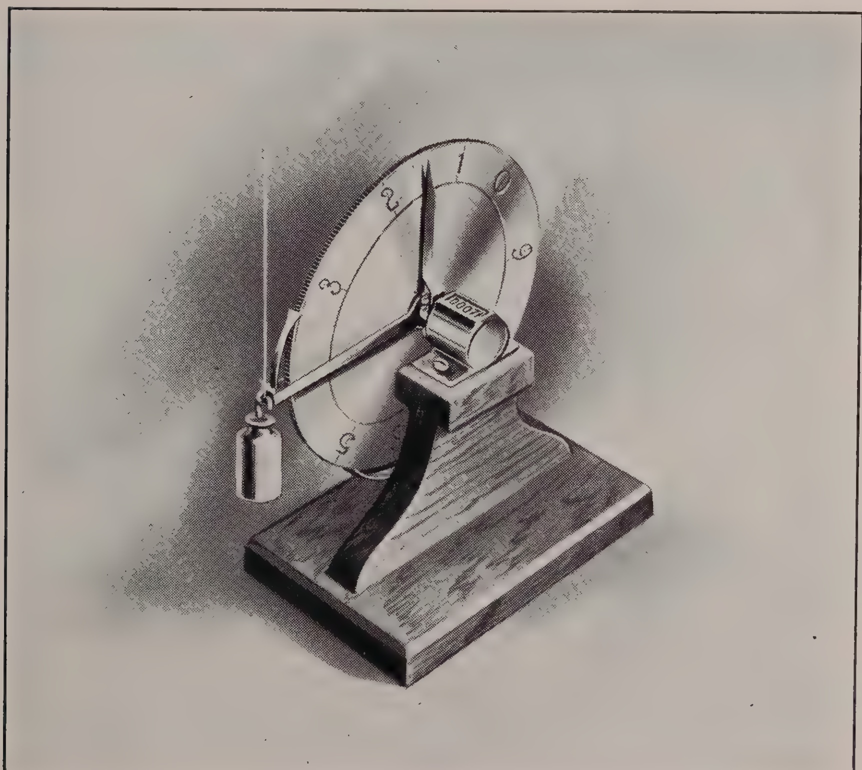

Fig. 8. Revolution counter used in later form of the ward crib recorder.

As yet no attempt has been made to measure the amount of increase in metabolism incidental to one complete revolution of the wheel, and it is a question whether quantitative values can be obtained with this device, especially for the comparison of results with different infants. But this method, which is inexpensive and simple, gives a general index of the degree of restlessness or muscular repose of infants, which should prove of value for ward use. This has already been shown in our more recent observations.

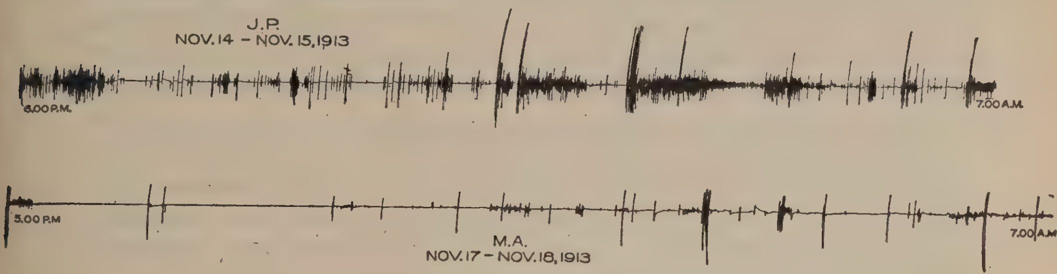

Fig. 9. Typical kymograph curves obtained with the ward crib recorder.

METHOD OF RECORDING THE PULSE-RATE.

Previous experiments with adults in the Nutrition Laboratory, in which the large respiration chambers were used, showed a striking relationship between the pulse-rate and the metabolism. Attempts were accordingly made to secure accurate pulse records in our observations with infants. For this purpose we attached the bell of a small Bowles stethoscope to the infant over the apex beat of the heart by means of strips of adhesive plaster. A rubber tube connecting with the bell led to a pipe in the wall of the chamber, a piece of rubber tubing and the earpieces being attached to the outer end of the tube. Even with a total length of some 2 or 3 meters from the bell to the earpieces, it was possible to count the pulse-rate of the weakest infant.

Since here again there is a direct connection between the inside of the chamber and the outside air, it is of the highest importance that the stethoscope and the rubber tube leading from it be tested for tightness. For this test, the stethoscope bell is immersed in water, and a slight pressure is put upon the diaphragm by blowing through the rubber tube. If it is not found absolutely tight, a thin coating of vaseline on the edge of the diaphragm usually insures a complete closure.

The importance of these pulse observations is so strongly impressed upon us that a special assistant is at present detailed in all of the experiments with infants for the sole purpose of recording the pulse-rate. The major muscular movements of the infant and any abdominal or chest sounds, such as grunting, sneezing, coughing, etc., may readily be heard through the stethoscope and are likewise regularly recorded upon the protocol sheet. It is also perfectly feasible to secure the respiration-rate in this way from time to time.

We are far from satisfied with this as a permanent method for securing a record of the pulse-rate, and it is our hope, in connection with the hospital or with the laboratory, to secure records either with the string galvanometer or with the Bock-Thoma oscillograph. It is clear that the records of the pulse-rate should be more objective than they can be even with a specially detailed assistant. During the experimental period, it is necessary to have the room absolutely quiet, and hence the assistant is not distracted by extraneous sounds. We regret, however, that a better method was not at the time practicable for recording a factor which is of such great significance in determining the general tonus of the body and therefore the basal metabolism.

GENERAL TECHNIQUE OF RESPIRATION EXPERIMENTS WITH INFANTS.

Previous to an observation, the length of the baby was measured by placing it upon a board with a head-board at right angles and a sliding foot-board. Subsequent to May 1, 1913, the infant was measured while flat on his back. Measurements were likewise taken of the circumference of the head above the ears, the chest over the nipples, and the abdomen over the umbilicus, as well as the greatest circumference of the thighs and the calves. The baby was also weighed naked. The rectal temperature was taken and recorded and the baby was given its food, except in certain instances when boiled water sweetened with saccharine was substituted. The infant was then immediately taken to the room in which the respiration chamber was placed.

Preliminary to the respiration experiment, the kymograph was wound, the wet bulb of the psychrometer thoroughly moistened with distilled water, the tambour tested under water to make sure that there was no defect in the rubber, and the pneumograph likewise tested for tightness. A sensitivity test of the apparatus was then made as previously described. In the bottom of the crib a small mattress or folded blanket was laid. The stethoscope was next properly adjusted by means of small strips of adhesive plaster and as soon as the infant was placed in the crib, the stethoscope tube was connected with the copper pipe in the wall leading to the earpieces outside. If the crib did not swing freely, the tension of the spring could readily be adjusted by raising or lowering a screw. In most instances, after placing the infant in the crib, it was found advantageous to pin the blanket in which it was wrapped at both the top and the bottom in the same manner that infants are wrapped when they are put to bed. The cover of the apparatus was then put on, the thermometer inserted in the top, the window covered with a black cloth, the ventilating current set in motion, and the time recorded.

The usual preliminary period sometimes lasted a considerable length of time, for it is obviously unwise to begin the first period of observation until the infant has been quiet for at least 15 minutes. The tempera-

ture of the water in the water jacket around the chamber was recorded and, if necessary, controlled by cooling during the period until the air inside the chamber, as recorded by the thermometer in the cover and by the thermometer in the outgoing air, had a temperature not far from 20° C. During this preliminary period, the air-current passed through one of the two sets of purifiers, the other set having previously been weighed and connected into position ready for use. Just prior to the end of the period, air was allowed to escape through a pet-cock in the system until the bell of the spirometer was about 30 mm. above the lowest point; the spirometer was then about half filled with oxygen, thus avoiding any possibility of there being a deficiency in the oxygen content of the air. While the rate of ventilation should be approximately constant, *i. e.*, about 35 liters a minute, it is practically impossible to regulate this unless a very constant electrical current is available. With the Crowell blower, as here used, about 270 revolutions a minute gives a suitable ventilation.

When the infant was perfectly quiet and the preliminary period was nearing the end, records were made of the readings of the wet- and dry-bulb thermometers, the thermometer in the top of the chamber, and the thermometer showing the room temperature. Air was then released from the system through the pet-cock until the spirometer pointer read about 30 mm. Inasmuch as there is a slight tension due to the uncompensated spirometer bell, the counterweight of the spirometer was taken in the hand and the bell gradually raised until the delicate petroleum manometer read zero. While the valves were turned to deflect the air-current from one set of air-purifiers to the other, the manometer was held at zero and the readings of the spirometer level taken immediately before and afterward. The beginning of the new period was marked on the kymograph record by the assistant, who then recorded the barometer reading and the temperature of the barometer. The readings on the oxygen meter having previously been taken or the oxygen cylinder carefully weighed, about one-half liter of oxygen was introduced or even more if the infant was very large or restless. This of course raised the spirometer bell. By determining the time in which the infant utilizes the half liter of oxygen, the oxygen supply can be regulated with considerable exactness, so that the spirometer reading will be nearly the same at the beginning and end of each period.

The length of a period of observation depends altogether upon the muscular repose of the infant, as only quiet periods, accompanied by a low pulse-rate, are of value. With a small, quiet infant, the periods may vary in length from 20 to 30 minutes, but with a large infant they may be as short as 15 minutes. About a minute and a half before the close of the period, the dry- and wet-bulb thermometers were again read, also the thermometer in the cover of the chamber, and the temperature of the room was recorded. The manometer was then adjusted

to zero, the spirometer read, and the valves turned, thus deflecting the air through the original set of absorbers, which in the interim had been weighed and again connected. In the middle of the period, a test for possible unabsorbed carbon dioxide was made by deflecting a small part of the air-current for a few moments through a solution of barium hydroxide in a small flask, returning the air to the system again to insure no loss of air from the chamber.

Throughout the entire period of observation, the pulse-rate was recorded every two minutes by a nurse, who made this her sole duty. Likewise other body movements distinguishable by means of the stethoscope, such as coughing, crying, or a deep breath, were noted and an occasional record made of the respiration-rate, which was counted directly from the stethoscope.

Occasionally the observations had to be interrupted because a change in position of the baby displaced the stethoscope and the pulse-rate could no longer be counted. Under such conditions, it was necessary to remove the cover of the chamber and reapply the adhesive plaster. The stethoscope caused the baby no discomfort at any time. The ward records were consulted to determine the normal or minimum normal pulse-rate and when the record reached this point and the kymograph showed that the infant was quiet, a period was started. At first the infant was observed through the window in the cover of the apparatus to see whether or not he was quiet, but in many instances it was found that infants which appeared absolutely quiet to the eye showed slight movements on the kymograph and the pulse-rate remained high. The visual estimation was therefore discontinued as being too inaccurate and unreliable a record of the degree of quiet.

The conduct of such an observation as has been outlined is not unlike the actual technique involved in a short-period alcohol check test, although the results of the short experimental periods with an infant are by no means as satisfactory. The temperature distribution throughout the chamber is more uneven in observations with infants; furthermore, the slightest movement of the infant may so disturb the temperature equilibrium that at the end of the period the temperature will be somewhat different from that at the beginning. Such changes, of course, affect the determination of the oxygen; as a result, the respiratory quotients for successive periods do not often agree. It is perfectly feasible, however, to determine the respiratory quotient during the entire period that the infant is inside the respiration chamber, independent of whether the subject is quiet or restless; as so determined, the respiratory quotient is an accurate indication of the character of the combustion. On the other hand, the determinations of the carbon dioxide for each individual period are extremely exact. It is possible, therefore, to utilize the carbon-dioxide measurements as an index of the total katabolism for each individual period and the respiratory

quotient for the whole sojourn inside the chamber as an index of the character of the combustion. It is thus perfectly logical to compute the indirect calorimetry from the measurements of the carbon dioxide and the calorific value of carbon dioxide for the particular respiratory quotient determined at the time.

This is the exact reverse of the method employed by Zuntz, who measures the oxygen consumption with great accuracy and computes the heat-output by indirect calorimetry, using the calorific value of oxygen with the various respiratory quotients. Theoretically either method gives reliable results and is without criticism. On the other hand, in experiments made with the respiration chamber, a rapid change in the value of the respiratory quotient is always possible. This is particularly true after feeding, since there may be a considerable rise in the respiratory quotient immediately after the food is taken, followed by a relatively rapid fall, thus materially affecting the indirect determination of the heat-output. Strictly speaking, therefore, the respiratory quotient should be determined for each individual period. As a matter of fact, in observations made a considerable time after the food had been taken, the respiratory quotient would remain relatively constant throughout the whole period of an hour or an hour and a half. In most of our observations the measurements of oxygen did not begin until some time after food was taken, and the preliminary period is not considered in our discussion of the respiratory quotient. While a gradual falling of the quotient would be expected as the time increased after food was taken, we have every reason to believe that, with the conditions obtaining in our observations, the actual fall in the quotient was very slight and could but rarely, if at all, affect the calculation of the indirect calorimetry. In this series of observations we have computed the indirect calorimetry from the direct measurements of the carbon dioxide, using the calorific values of carbon dioxide[1] for the respiratory quotients obtained during the experimental period.

The fact should again be emphasized here that tests for tightness and efficiency preceded every individual observation and check tests for determining the respiratory quotient with alcohol were made once a week.

The later method for determining the absolute amount of alcohol burned and the respiratory quotients for short periods approximating the periods of observation with infants was not perfected until the fall of 1913; nevertheless we feel confident that the number of control tests made with the older method in connection with these researches is fully justified in order to secure absolute accuracy in this, the first extensive use of the apparatus for studying infant metabolism.

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[1]See table 15, p. 29.

PART II.

STATISTICS OF OBSERVATIONS.

SELECTION OF SUBJECTS.

The infants studied were all kept in the children's ward of the Massachusetts General Hospital and were selected for the most part from those coming to the Out-Patient Department; a few came directly from the Boston Lying-in Hospital. In many instances they were placed in the wards for the purpose of having their digestion studied; in a few cases they came because of some slight indigestion or because they were not gaining weight satisfactorily.

Each infant that enters the children's ward of the Massachusetts General Hospital has a complete physical examination, including an examination of the ear drums; careful notes are also made as to the general appearance, actions, and digestion. When the physical examination of the infants selected for observation was normal—in most instances the records were naturally of a negative nature, as for example "no enlargement of the peripheral lymph nodes"—and the infant led a regular and uneventful life, it was considered a normal infant. In some instances the subjects were below weight but appeared normal in other ways. In such cases, the fact is recorded in the statistics.

The infants were under the general care of one of us who saw them each day, but the immediate care was detailed to the house physician and excellent trained nurses. The routine throughout the day was regular. They were weighed naked at the same hour each day by the same nurse. The nurses also recorded carefully how much food was eaten; the percentages of the food components given and the number of calories in the food taken were roughly calculated for each day. Notes were kept as to the character of the dejections, and the pulse-rate and body-temperature were recorded twice a day. The clothing was the ordinary clothing used in hospitals for infants of their age; the beds were the usual hospital cribs. The house officer took careful histories of all the infants, his physical examination and bedside notes being verified by one of us. These records were made and the infant studied before any observations were made of the metabolism in order to control all factors so far as possible.

Infants who were quiet and comfortable were considered to be the most favorable subjects for observation, but we were frequently disappointed in the results, as many infants who were supposed to be absolutely quiet during the 24 hours did not prove to be so. This

led us to install in the ward a crib so adjusted as to give kymographic records of the degree of activity or quiet, like those obtained with the respiration chamber.[1] The infant selected for observation was placed in this crib for 24 or 48 hours and a graphic record of his muscular activity secured for the whole period. In one instance an infant who was said to be the "quietest baby in the ward, hardly moving all day," gave a surprising record in that it showed that she actually moved a great deal and that there were only a few hours out of the whole 24-hour day in which she was truly quiet.

HOSPITAL RECORDS.

The routine histories, records of the physical examinations, notes regarding the urine, stools, blood, and temperature, the pulse and respiration charts, and detailed records of the food were kept for all of the infants. The Wassermann reaction and the von Pirquet skin tests were also made in many of the cases noted in the statistics. It does not seem desirable to publish the complete hospital record of each infant that came under observation, as such an amount of detail would make it impossible to find the essential points without too much labor. This is particularly true because most of the evidence is negative as to whether or not an infant is normal. One complete record of a typical case will therefore be given and only such information recorded for the other cases as has a bearing on the metabolism or is pathological in character.

TYPICAL RECORD.

Subject, F. B. Male; date of admission to hospital, April 22, 1913; age, $5\frac{1}{2}$ months.

Preliminary diagnosis. Feeding.

Family history. Father and one other child living and well. Mother lame from an old infantile paralysis. She was operated on in the Massachusetts General Hospital a year ago for "intestinal obstruction" which came on when she was 2 months pregnant.

Past history. Full term, instrumental delivery. Birth-weight, 4.54 kg. Breast-fed, 6 days, then mother had blood poisoning and infant was weaned.

Present illness. From the age of 10 days until admission to the hospital, has had recurring boils on different parts of the body. Was fed for two months on modified milk and lactose and after that a proprietary food was substituted for lactose because he was not doing well. Is now getting 2.7 per cent of fat, 8 per cent of sugar (extra sugar in the proprietary food), 2.1 per cent of protein, 6 feedings of 5 ounces. Takes bottle well, does not vomit. Is very constipated in spite of magnesia and orange juice.

Physical examination. Fairly developed, poorly nourished. Bright and intelligent. Strong cry. Almost no subcutaneous fat. Muscles small but firm. Holds head up and sits up without support. Skin of trunk shows scars of old furuncles and on scalp are two which have almost healed. There is a fine papular eruption on back of neck and between shoulders. Head well shaped. Anterior fontanelle depressed and measures 2×2 cm. in diameter.

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[1]For description see p. 59.

Posterior fontanelle closed. Sutures closed. No craniotabes. Parietal bones not prominent. Eyes: No discharge; pupils equal and react to light; external ocular movements normal. Ears: No discharge; tympanic membranes normal. Nose: No discharge; alæ nasi do not move with respiration. Mouth: Mucus membrane, good color; no teeth; in center of hard palate is an oval ulcer about 1 cm. long in diameter, which is shallow and apparently filled with granulations; tonsils not prominent or reddened; pharynx normal. Glands: Axillary normal; epitrochlears normal; submaxillary, cervical, posterior auricular, occipital, inguinal, and femoral glands all enlarged and vary in size from a pea to a large bean; are hard and non-tender. Chest: Symmetrical; expansion equal; very slight rosary; no Harrison's groove. Heart: Apex impulse felt in fourth space, 4 cm. from midsternum; dulness corresponds; right border 1 cm. from midsternum; upper border at third rib; sounds regular and of good quality; no murmurs; pulmonic second louder than aortic second. Lungs: Normal resonance, fremitus, and breath sounds; no râles. Abdomen above level of thorax, soft, very tympanitic. Moderate diastasis of recti. No masses or tenderness. Liver dulness extends from fifth space to 1 cm. below costal margin, where smooth edge is felt. Smooth edge of spleen is felt 3 cm. below costal margin. Genitalia normal. Extremities normal. No paralysis, contractures, or edema. Epiphyses of long bones not enlarged. Reflexes: knee-jerks present and equal. No Kernig sign. No stiffness of neck or neck sign.

April 22. Blood: Hæmoglobin, 70 per cent (Talquist); white count, 10,000. Smear normal. Polynuclears, 32 per cent; small lymphocytes, 20 per cent; large lymphocytes, 47 per cent; endothelial cells, 1 per cent. Wassermann reaction suspicious.

April 23. Urine: Pale; clear; acid; albumin, slightest possible trace. No sugar. Urobilinogen absent. Sediment, a few round cells. Stool: Greenish brown; pasty; normal odor; acid to litmus paper; few soft curds, no tough curds; little finely divided mucus.

April 24. X-ray examination immediately after bismuth feeding, and every hour thereafter for several hours.

April 25. Von Pirquet skin tuberculin, negative 48 hours. Stool: Greenish yellow and black; crumbly; acid; no curds. Bismuth in large amount. Total fat in moderate excess.

April 26. X-ray examination as before.

April 27. Stool: Yellowish-white and black mixed (bismuth); acid; normal odor; few soft curds; total fat in moderate excess.

April 28. Stool: Soft yellow; acid; many small soft curds, few tough curds; no mucus; total fat in moderate excess. X-ray examination as before. Takes bottle well; gaining weight in spite of starvation.

May 2. Summary: Underfed; under-weight; bright, happy infant; very active; always hungry for bottle; takes it quickly; not quite satisfied. Discharged, relieved, Out-Patient Department. Diagnosis: Feeding; syphilis (?).

The chart for this infant during his stay in the hospital is given in figure 10. This shows curves for records of the body-temperature, the pulse-rate, the respiration-rate, the body-weight, and the calories per kilogram of body-weight contained in the food.

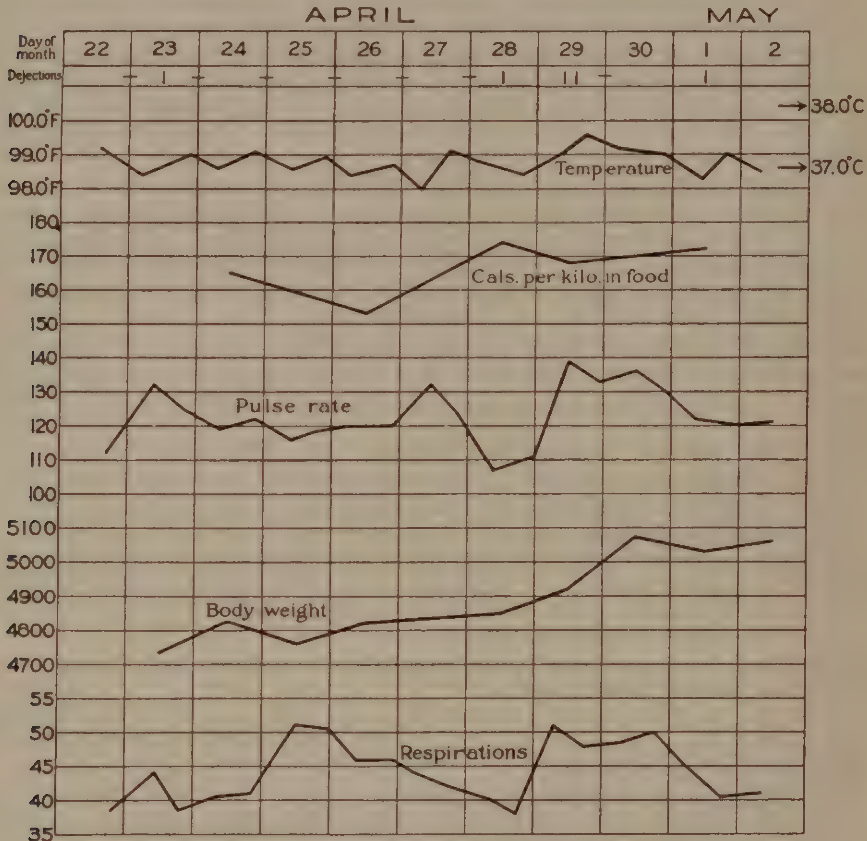

Fig. 10. Hospital chart for F. B.

One dejection in evening is indicated by —; one dejection during day by |; two dejections during day by ||. The records of the temperature were taken in the rectum.

This infant weighed about 2 kilograms less than the average weight for the age, and 3 kilograms less than he would have weighed had he developed in the normal manner. He was very much under weight, but gained consistently while in the hospital. He was considered to be in the convalescent stage of infantile atrophy. The daily records of the food, dejecta, and body-weight are given in table 21.

TABLE 21.—*Record of food, dejecta, and body-weight.*

Date.	Food.	Dejecta.	Body-weight.
1913.			*kilos.*
Apr. 22–23.	3 p. ct. fat; 6 p. ct. lactose; 1.4 p. ct. protein. 180 c.c. at 3, 6, and 10 p. m., $2^h 30^m$ and 6 a. m.	2 greenish yellow and brown stools with many small soft curds and little mucus.	4.750
23–24.	3 p. ct. fat; 6 p. ct. lactose; 1.6 p. ct. protein. Extra sugar lactose. 180 c. c. at 9 and 12 a.m.; 210 c.c. at $2^h 15^m$ p.m.; 195 c.c. at 6 and 10 p.m., 2 and 6 a.m. Total amount for day, 1350 c.c.	1 small constipated stool with fat curds.	4.825
24–25.	One feeding water, 90 c.c., whole milk, 120 c.c., bismuth, 30 gm. total (210 c.c.) at 9 a.m. Water, 210 c.c. at $2^h 20^m$ p.m. Regular formula as on Apr. 23–24: 195 c.c. at 8 a.m., 90 c.c. at 10 a.m.; 195 c.c. at 2 and 6 p.m. Total for day, 1095 c.c.	1 large constipated stool with many soft curds. 1 large dark green dry stool. Acid.	4.750
25–26.	Regular formula: 195 c.c. at 9 and 12 a.m., $2^h 15^m$ and 6 p.m.; 180 c.c. at 10 p.m.; 195 c.c. at 2 and 6 a.m. Total amount for day, 1350 c.c.	1 large soft dry yellowish green stool with many soft curds. Acid.	4.815
26–27.	One feeding whole milk, 120 c.c., bismuth, 30 gm., lime water, 24 c.c., water, 64 c.c. (total, 210 c.c.) at 9 a.m. Regular formula: 195 c.c. at $2^h 15^m$, 6 and 10 p.m., 2 and 6 a. m. Total for day, 975 c.c.	1 large green and white movement with many soft curds. Acid.	4.825
27–28.	Regular formula: 195 c.c. at 9 and 12 a.m.; 210 c.c. at 3, 6, and 10 p.m., 2 and 6 a.m. Total amount for day, 1440 c.c.	1 large spongy yellowish green stool with many soft curds. Acid.	4.850
28–29.	Regular formula: 195 c. c. at 9 a.m. and 10 p.m.; 210 c.c. at 12 a.m., 3 and 6 p.m., 2 and 6 a.m. Total amount for day, 1440 c.c.; vomited about 30 c.c.	1 large soft formed yellow stool with many soft curds. Acid.	4.925
29–30.	1 feeding of whole milk, 120 c.c., bismuth, 30 gm., lime water, 60 c.c., water, 30 c.c. (total, 210 c.c.) at 9 a.m. Regular formula: 210 c.c. at $2^h 15^m$, 6 and 10 p.m., 2 and 6 a.m. Total amount for day, 1260 c.c.	2 large yellowish gray stools with many soft curds. 1 large yellow and very dark green stool with curds. Acid.	5.100
April 30 to May 1.	Regular formula: 210 c.c. at 9 and 12 a.m.; 3, 6, and 10 p.m., 2 and 6 a.m. Total amount for day, 1470 c.c.	2 somewhat constipated yellow stools with specks of mucus. Acid.	5.025
May 1–2 . .	Regular formula: 210 c.c. at 9 and 12 a.m.; 3, 6, and 10 p.m., 2 and 6 a.m. Total amount for day, 1470 c. c.	2 large yellow rather constipated stools with soft curds and little mucus. Acid.	5.050

SUMMARIZED HOSPITAL RECORDS FOR OTHER SUBJECTS.

Instead of giving the detailed records for each subject, as in the case of F. B., summaries of the hospital records are presented herewith which include all data of value in studying the results of the metabolism observations. These summaries are arranged in alphabetical order, and may thus be readily referred to.

Subject, M. A. Male; born February 11, 1913; birth-weight, 3.75 kilograms.

Previous to coming to the hospital, this infant had been breast-fed at intervals of 2 to 3 hours. Although never acutely ill, he had not gained weight as rapidly as the average infant, and had never been very strong. He usually

passed 4 to 6 stools a day. An analysis of his mother's milk showed that it was very weak. He entered the hospital when 9 months old (November 3, 1913), with a severe secondary anæmia. His weight at that time was 5.70 kilograms. When the blood was examined, it was found that while the differential count of the white cells was normal, there was but 35 per cent of hæmoglobin (Talquist), 18,000 white blood corpuscles, and 2,712,000 red cells. The Wassermann reaction was negative. The physical examination showed that the infant was well developed and fairly nourished. The skin and mucous membrane were of a pale lemon color. The edge of the liver was felt 2 cm. below the edge of the ribs and the spleen was hard, extending down to the crest of the ileum. There was but a small amount of subcutaneous fat. The digestion was normal, but it was often necessary to feed him with a stomach tube. When discharged from the hospital on December 27, 1913, he weighed 5.60 kilograms. The case was diagnosed as splenic tumor with a severe grade of secondary anæmia. His weight on entering the hospital was 2.8 kilograms less than the average for an infant of his age.

Subject, J. B. Male; born October 19, 1912; birth-weight unknown.

This infant entered the skin ward of the Massachusetts General Hospital on February 21, 1913; his weight at that time was 3.06 kilograms. He was described as a poorly developed and nourished infant with an eruption typical of congenital syphilis. After inunctions of mercury were given him, the external evidence of syphilis disappeared. The physical examination was otherwise normal. During the 5 weeks this infant remained in the hospital he gained very little until the week preceding his discharge, when he gained approximately 0.5 kilogram, weighing when discharged 3.74 kilograms. His case was diagnosed as one of hereditary syphilis. He was very much underweight, weighing about 3 kilograms less than the average weight for his age. During the last week he was gaining weight and therefore may be considered as in the convalescent stage of infantile atrophy with syphilis.

Subject, L. B. Female; born at full term in September, 1912; birth-weight, 3.86 kilograms.

She was breast-fed for the first 2 months and subsequently fed on a mixture of milk, a proprietary food, and water. Her digestion was poor and she lost a little weight. She entered the hospital January 24, 1913, age 4 months, to have her metabolism determined. At this time she was a small, thin, but healthy-looking infant, with but little subcutaneous fat. She was not emaciated, however, and appeared well. She held up her head, but could not sit up without support. Her physical examination was normal. She was fed on modified milk in the usual proportions, her weight increasing from 3.89 kilograms to 4.07 kilograms, after which she ceased to gain. She was moderately under weight, as the average weight for an infant of 4 months is 6.25 kilograms. If she had grown in the usual way from birth, she would have weighed about 0.5 kilogram more than the average weight for an infant of this age. The hospital diagnosis was "regulation of feeding."

Subject, L. R. B. Female; born June 24, 1913; birth-weight, 4.08 kilograms.

This infant had always been breast-fed and had gained in the usual manner. She entered the hospital when 4 months old (October 31, 1913), to have her metabolism determined, and for weaning, as the mother was obliged to work. The physical examination showed that she was a well-developed, well-rounded infant, with the normal musculature and subcutaneous fat. The organs were all normal. On November 1 and November 3, modified milk was given her

containing about 88 calories per kilogram of body-weight. On November 5, she was given milk containing 103 calories per kilogram of body-weight. The temperature was normal. Her weight was 6 kg; the average weight for an infant of her age is 6.25 kg.; she was therefore a perfectly normal infant.

Subject, A. C. Female; born February 2, 1913; birth-weight, 3.09 kilograms.

Her history was unimportant, and her physical examination normal. When she entered the hospital March 19, 1913, at the age of 6½ weeks, she was a strong, well-developed, and well-nourished infant. During her stay in the hospital she was fed with modified milk of the ordinary proportions and showed no signs of indigestion other than the occasional spitting up of small amounts of food. Her diet contained about 100 calories per kilogram of body-weight; with this diet her weight decreased in one week from 3.02 kilograms to 2.92 kilograms. Her temperature was normal except for two instances when it rose for no cause that could be discovered. She was to all appearances a normal infant. She weighed 0.4 kilogram less than the average weight for the age, but since she weighed 0.3 kilogram less than the average at birth this may be deducted from the average weight to show her expected weight for the age.

Subject, M. C. Female; born August 31, 1913; birth-weight, 4.09 kilograms.

She was breast-fed for a month and a half after birth and was then given modified milk; she had always been well. When 4 months old (January 1, 1914), she entered the hospital to have her metabolism determined; her weight at this time was 6 kilograms. The physical examination was normal and there was a normal amount of subcutaneous fat and muscle. Her temperature was normal throughout her stay. The average weight for an infant of this age is 6.25 kilograms; she was therefore approximately the weight of the average infant and on this basis may be considered a normal infant. As she weighed 0.68 kilogram more at birth than the average infant, she was approximately 0.75 kilogram below the weight she would have been had she gained in the usual manner.

Subject, A. D. Female; born December 28, 1912; birth-weight, 2.36 kilograms.

Previous to coming to the hospital she had always been fed on modified milk. She cried considerably and vomited immediately after almost every feeding. The milk formula had been changed, a month previous, to equal parts of cream, water, and lactose in amounts that gave her about 50 calories per kilogram of body-weight. She entered the hospital when 4 months old (April 26, 1913), with the provisional diagnosis of starvation. Her weight at that time was 2.55 kilograms, which was less than half of what she would have weighed had she gained in the normal manner, and 3.70 kilograms less than the average for an infant of that age. She was a poorly developed, poorly nourished, emaciated, and "dried up" infant, with a fairly strong cry and a feeble grasp. There was no subcutaneous fat and the muscles were small and weak. After coming to the hospital, she was fed on modified milk and gained rapidly in weight from May 1, when she weighed 2.60 kilograms, to June 5, when she weighed 3.70 kilograms. On May 18 it was noted that she was gaining very rapidly in weight and strength, and that her general appearance was improving. The digestion and temperature were normal except on the afternoon of May 24, when the temperature was 36.1° C. (97° F.). At the time of her discharge from the hospital, she weighed about 2 kilograms less than she would have if she had gained weight in the usual manner, and 3 kilograms less than the average weight of an infant of her age (5 months). She

was therefore markedly under weight as a result of improper food and was on the border line of infantile atrophy. When her food was regulated, her digestion became good and she gained weight rapidly. She could be considered as being in the stage of convalescence.

Subject, M. D. Male; born February 23, 1913; birth-weight unknown.

He entered the hospital March 8, 1913, at the age of 2 weeks, to have his metabolism determined. Before coming to the hospital he had been fed partly on modified milk and partly at the breast. His history was negative. He was a well-developed, strong, well-nourished infant, who was normal in every way. While in the hospital, he was given modified milk. His digestion remained good but he did not gain in weight, presumably because he only received 80 to 90 calories per kilogram of body-weight. He weighed 4.05 kilograms, which was about the average weight for an infant of his age.

Subject, R. E. Male; born July 22, 1913; birth-weight, 2.27 kilograms.

His history was negative except for the fact that he had twice had jaundice. Previous to coming to the hospital, he had been fed on modified milk; his digestion was normal. He entered the hospital when 4½ months old (December 4, 1913), for the purpose of having his metabolism determined. The physical examination showed that he was well-developed and nourished, with firm musculature and considerable subcutaneous fat, though not an excessive amount. He was otherwise physically normal. The temperature varied between 36.4°C and 38.0° C. (97.6° F. and 100.4° F.). On entering the hospital, he weighed 5.1 kilograms; as the average weight for an infant of his age is 6.5 kilograms, he was 1.4 kilograms under weight, but since he weighed 1.1 kilograms less than the average at birth he was only 0.3 kilogram below his expected weight. He was otherwise a physically normal infant.

Subject, E. F. Male; born September 3, 1913; birth-weight, 4.22 kilograms.

He had always been breast-fed and thrived in every way. He was brought to the Out-Patient Department of the hospital, when 3 months old, for the purpose of having his metabolism determined. The physical examination showed that he was a well-developed, well-rounded infant, with a normal amount of subcutaneous fat. The average weight of an infant of his age (3 months) is 5.56 kilograms. At birth he was 0.8 kilogram heavier than the average infant, and with normal development he would be expected to weigh 6.36 kilograms at this age. He actually weighed 7.05 kilograms, or approximately 1.5 kilograms above the average weight for this age and 0.7 kilogram above what he would have weighed with normal development. He was therefore a perfectly normal infant.

Subject, E. G. Male; born January 23, 1913; birth-weight, 3.63 kilograms.

For the first 8 months after birth he was breast-fed and subsequently fed on modified milk. He had always thrived on this food. When 10 months old, he entered the hospital on November 25, 1913, to have his metabolism determined and for weaning. On physical examination he was found to be a normal well-developed and very well-nourished infant, with firm muscles and deep layers of subcutaneous fat. He had 4 teeth. His temperature was normal. His weight was 9.55 kilograms; the average weight for an infant of this age (10 months) is 8.75 kilograms; he was therefore 0.8 kilogram above the average weight and 0.6 kilogram above the expected weight. He may be characterized as a large, fat, normal infant.

Subject, E. K. Male; born at full term July 13, 1912; birth-weight unknown.

He was breast-fed for 2 months; subsequently he was given modified milk, and more recently was fed from the family table. He had never been well and when brought to the hospital on November 29, 1913, he was found to have broncho-pneumonia and rachitis. The metabolism was determined a week after he had recovered from the pneumonia. He was physically a fairly well-developed and nourished infant with a moderate amount of subcutaneous fat. When his metabolism was determined, his weight was only 8.03 kilograms, which is the average weight for an infant of 8 months, so that for an infant of 17 months he was very much under weight.

Subject, F. K. Male; born October 4, 1912; birth-weight, 3.54 kilograms.

For the first 3 months he was fed at the breast; he vomited considerably, was cross and fretful, and did not gain in weight. He was then weaned, and at first given modified milk, and later condensed milk, but without improvement, as he continued to vomit and to pass 6 to 8 loose green stools a day. He entered the hospital on May 1, 1913, at the age of 7 months. At that time he was a fairly developed and nourished infant, with a considerable amount of subcutaneous fat and firm muscles. The physical examination was normal. He was fed with modified milk having a caloric value of about 140 calories per kilogram of body-weight. His digestion and temperature were normal; he did not vomit during his stay in the hospital. His weight was 5.65 kilograms when he entered the hospital and 5.75 kilograms at the time of his discharge on May 11. He was about 1.5 kilograms lighter than the average for his age, but was otherwise perfectly normal.

Subject, A. L. Female; born at full term Mar. 2, 1913, birth-weight, 3.64 kg.

Previous to entering the hospital, she had been fed at the breast, but had been given supplementary feedings of a proprietary food and milk for a short time. She had always vomited more or less after the feedings and had recently been losing weight. Her weight on entering the hospital June 5, 1913, was 3.10 kilograms. The physical examination showed her to be a poorly developed, poorly nourished, and emaciated infant, with almost no subcutaneous fat. All of the peripheral lymph glands were slightly enlarged and there was a slight rosary. The other organs were normal. She was given a diet of modified milk during her stay of 6 weeks in the hospital; on her discharge she weighed 3.20 kilograms. The hospital diagnosis was "regulation of feeding." Since the average weight at 4 months is 6.25 kilograms and the expected weight would be essentially the same, she was about 3 kilograms under weight when discharged from the hospital.

Subject, E. L. Male; born January 19, 1913, of syphilitic parents; birth-weight unknown.

This infant was breast-fed for 1 month, then fed on modified milk, but was not satisfied with the food and did not gain in weight. He entered the hospital on May 15, 1913, at the age of 4 months. When examined he was found to be a rather small, fairly nourished infant, that lay quietly in the nurse's lap. He could not hold his head up. The skin was lax, with small amounts of subcutaneous fat. The physical examination was normal except that the edge of the spleen was felt just below the costal margin. The Wassermann test of the blood on May 20 was negative. He was fed with modified milk supplying approximately 120 calories per kilogram of body-weight. The temperature was normal. He had a chronic otitis media which required paracentesis five times while he was in the hospital. Any digestive disturbance during his stay was probably secondary to the infected ears. His weight on entering the hos-

pital was 4.15 kilograms; on June 1, 4.48 kilograms; June 12, 4.48 kilograms; and on June 18, 4.68 kilograms. Since the average weight for 4 months is 6.25 kilograms, he was about 1.75 kilograms under weight.

Subject, R. L. Male; born at full term Aug. 14, 1912; birth-weight, 2.27 kg.

He entered the hospital on February 24, 1913, and an operation was performed for hare lip and cleft palate on March 12. The temperature became elevated after the operation and on the 16th a typical measles rash appeared. The temperature dropped to normal on March 22. He was discharged from the hospital on March 27. On April 5 he again entered the hospital with a high fever, a right upper lobar pneumonia, and infected ears. The temperature dropped to normal on April 19 and remained there until April 26, when he had pneumonia for a second time, which continued 8 days. On May 6 a double paracentesis was again necessary and from that time on there was no elevation of temperature. He was a large, well-developed, and well-nourished infant, with normal digestion. On April 15 he weighed 7.60 kilograms, while on May 16 he weighed 7.30 kilograms. At the age of 8 months, therefore, his weight was 0.47 kilogram less than the average for that age; on May 16, when he was 9 months old, he had lost weight and was about 1 kilogram below the average weight. On the other hand, as he was 1 kilogram or more under weight at birth, he was a little over the weight which would be expected with normal development.

Subject, D. M. Male; born April 24, 1912; birth-weight, 3.00 kilograms.

This infant was prematurely born at $8\frac{1}{2}$ months. He was breast-fed for the first 5 weeks and subsequently fed on various modifications of milk, malted milk, and condensed milk. During November, 1912, he gained practically no weight and had frequent colds and pertussis. On February 24 he was brought to the Out-Patient Department of the hospital with a double otitis media. Later he had chicken pox. He entered the hospital when he was 11 months old (March 25, 1913). At that time he was found to be a fairly developed and nourished infant, with a small amount of subcutaneous fat and soft muscles. He was unable to sit up without support, the back showing a marked curve of weakness. The head was square, with a flat top and prominent parietal eminences. There was a slight rosary, but no enlargement of the epiphyses. The physical examination was otherwise normal. Despite the infected ear, the temperature did not rise higher than 37.78° C. (100° F.) during his stay in the hospital. He was given milk modified to suit his digestion, with a fuel value of about 140 calories per kilogram of body-weight. During the first few days he did not take the food from the bottle well, but after he had become accustomed to his surroundings, he gained in both weight and appearance, the gain in his general condition being much more than the weight indicated. When he entered the hospital, he weighed 5.20 kilograms; this weight fell to 5.10 kilograms on March 29, after which there was a gain until he was discharged in April, when he weighed 5.23 kilograms. He was about 4 kilograms below the average weight for his age, and about 3.6 kilograms below what he would have weighed had he gained in the usual manner.

Subject, F. M. Male; born September 13, 1912; birth-weight unknown.

His past history was unknown. When he entered the hospital on January 16, 1913, he had congenital syphilis, with a positive Wassermann reaction. The general physical examination was normal except that he was under weight, weighing only 4 kilograms, while the average weight for an infant of this age (4 months) is 6.25 kilograms. His temperature and digestion were normal.

Subject, J. M. Male; born July 28, 1912; birth-weight not known.

For the first two weeks after birth he was breast-fed; subsequently he was given whole milk diluted with water, which seemed to agree with him. Then he had diarrhea and was fed condensed milk. When 5 months old he was brought to the Out-Patient Department of the Massachusetts General Hospital, as he was constipated and not gaining. His weight on January 9 was 5.20 kilograms, or 1.60 kilograms below the average weight for this age (5 months). He was given milk suitably modified and gained weight slowly, his stools showing good digestion. About this time he had several colds. On March 6 he developed an acute otitis media which necessitated opening both ear drums; the discharge from the ears persisted up to the date of his entrance to the hospital ward on March 27, 1913 (at the age of 8 months). At this time he was found to be fairly well-developed and nourished, with a moderate amount of subcutaneous fat. The head was somewhat square and there was a slight rosary. There was a purulent discharge from both ears. All the peripheral glands, including the epitrochleas, were easily palpable, being the size of small shot. The physical examination was otherwise normal. Although the discharge from the ears continued, the ear infection caused no elevation of temperature after April 1 and no other symptoms. He was given milk modified to suit his digestion, with a fuel value of about 140 calories per kilogram of body-weight. His digestion was normal. At the time he entered the hospital, his weight was 5.50 kilograms; when he was discharged it was 5.63 kilograms, these weights being about 2.5 kilograms below the average for his age (8 months).

Subject, M. M. Female; born January 21, 1913; birth-weight, 3.18 kilograms.

She was fed on modified milk and did well until several days before coming to the hospital, when she began to vomit after feeding and to have diarrhea. Her mother gave her one-half ounce of castor oil and changed her diet to barley water. The infant entered the hospital on May 28, 1913. The physical examination showed her to be well-developed, strong, and bright, with a good amount of subcutaneous fat. The skin was a little loose, indicating a recent loss of flesh, but otherwise the examination was normal. The temperature, which was elevated on the day of admission, soon dropped to normal. She was given weak mixtures of modified milk which contained about half as much food as she required to gain weight. Her weight remained stationary at 5.35 kilograms. This was about 1.15 kilograms lighter than the average weight for an infant of her age ($4\frac{1}{2}$ months) and about 1 kilogram lighter than she would have been had she developed consistently from birth. The diagnosis was acute gastro-intestinal indigestion.

Subject, E. N. Female; born November 17, 1912; birth-weight not known.

Previous to coming to the hospital she had been fed on various proprietary foods, separately or in combination. She cried considerably and was hungry. She did not vomit and her stools were soft, green, and foul. When she entered the hospital on May 19, 1913, she was found to be a well-developed and fairly well-nourished infant, with a strong cry. The subcutaneous fat was in small amounts; the skin was lax and the muscles flabby, but the grasp was strong and she was able to hold her head up. The rest of the physical examination was normal. She cried very little while in the hospital, but "ate, laughed, and slept." Her weight on entering was 5.40 kilograms and on her discharge on June 2, 1913, it was 5.26 kilograms. She was 2 kilograms below the average weight for an infant of her age (6 months), but was otherwise normal in all respects. Her case was considered to be one requiring a regulation of feeding, her condition being due to improper feeding, with probably too much carbohydrate. No permanent injury had been done, as her

digestion quickly became normal when she was given milk properly modified, with a fuel value of about 140 calories per kilogram of body-weight.

Subject, L. O. Male; born September 5, 1912; birth-weight, 3.75 kilograms.

This infant had always been fed with the bottle on mixtures of various proprietary foods, with little or no cow's milk. He lost weight on this diet and had never regained his birth-weight. When he entered the hospital at the age of $4\frac{1}{2}$ months (January 29, 1913), the physical examination showed that he was a small, rather emaciated infant with a pinched face and practically no subcutaneous fat. The musculature was slightly flabby and he was unable to hold up his head. The cry was fairly strong and he seemed bright. The physical examination was otherwise normal. His weight on entering the hospital was 2.93 kilograms and it continued about the same until approximately February 15, when he began to gain slowly. On March 10 he weighed 3.32 kilograms. After that date his temperature was elevated and it was discovered on March 14 that he had measles. During the period when his metabolism was being determined, his temperature in the wards varied between 36.1° C. (97° F.) and 36.7° C. (98° F.), being subnormal in the morning and usually reaching 36.7° C. (98° F.) in the afternoon. On March 12, the temperature became elevated with the prodromal symptoms of measles.

He was a very much under-weight and under-nourished infant, with an indigestion which was presumably due in the first place to too much sugar in the diet and secondly to too much fat. There was no difficulty in digesting protein in relatively large amounts. His diet during his stay in the hospital was cow's milk modified to suit his digestion, and on this he gained slowly and consistently in weight until he had measles. The stools were at first loose, watery, and acid, but after the food was regulated they became firm, solid, and alkaline. He weighed less than his birth-weight when he should have weighed almost double his birth-weight; taking into account the subnormal temperature, general appearance, and history, he might be considered a case of infantile atrophy.

Subject, J. P. Male; born prematurely at 7 months April 11, 1913; birth-weight, 2.05 kilograms.

He was never breast-fed, but was given condensed milk, or modified milk with a proprietary food; he had never thrived on this diet. He entered the Floating Hospital August 14, 1913; his physical examination was negative at this time, except for emaciation. He gained in weight up to 4 kilograms, but then had indigestion, and was given a formula containing malt soup, which resulted in a gain in weight up to 4.54 kilograms. On September 12, 1913, he entered the Massachusetts General Hospital and was found on physical examination to be moderately emaciated, with an indigestion due to too large a proportion of fat in the diet. He was put on a diet of modified milk, regulated to his digestion, and on September 28 began to gain rapidly. On October 25, he weighed 5 kilograms and on November 8, 5.5 kilograms. He was happy and smiling, well covered with fat, and his physical examination was normal. He was, however, approximately 2 kilograms under weight, as the average weight for his age (7 months) is 7.7 kilograms. Since he weighed 1.35 kg. less than the average at birth, he would have weighed 6.4 kg. if he had gained normally. On this basis, he weighed 0.9 kg. less than he should have weighed.

Subject, W. P. Male; born August 23, 1912; birth-weight, 2.73 kilograms.

His history previous to his coming to the hospital was unimportant, save that his food contained practically no fat, he was very constipated, and not gaining in weight. On January 24, 1913 (age, 5 months), he entered the hospital ward to have his metabolism determined. At that time he was an

undersized and rather poorly nourished infant, with but a small amount of subcutaneous fat. He noticed objects, and held up his head, but could not sit up without support. His physical examination was normal except that there was a slight rosary. While in the hospital he kicked and laughed a good part of the day while awake, slept 6 hours during the day and all night except when fed at 10 p. m., 2 a. m., and 6 a. m., and was considered a particularly happy infant. He made slow but consistent gains without symptoms. His food was modified milk and his digestion was normal. When he entered the hospital, his weight was 4.14 kilograms and on February 2 (9 days later), 4.39 kilograms. When discharged from the hospital, he was about 1 kilogram below the weight he would have been if he had doubled his birth-weight in 5 months and 2.5 kilograms below the average weight for a baby of his age.

Subject, D. Q. Male; born at full term on Aug. 2, 1913; birth-weight, 2.5 kg.

He was breast-fed for the first 2 months, and subsequently on modified milk. When on the latter food, he had diarrhea in December, but when the formula was modified the digestion became perfect. He entered the hospital on December 22, 1913, at the age of 4½ months, for the purpose of having his metabolism determined. He was then reported as gaining rapidly. He was well-developed and nourished, with firm muscles, and a well-developed layer of subcutaneous fat. Both the physical examination and the temperature were normal. He was under weight, as he weighed only 5.2 kilograms and the average weight for this age is 6.5 kilograms. His birth-weight was, however, 0.9 kilogram less than the average infant at birth and if he had gained normally he would have weighed approximately 5.6 kilograms. He was, therefore, 0.4 kilogram below what he should have weighed.

Subject, E. R. Male; born January 12, 1913; birth-weight, 2.95 kilograms.

His father was unknown; his mother was treated for syphilis by two injections of salvarsan during pregnancy. During the first seven weeks he was breast-fed; subsequently he was fed both breast and modified milk on which he did well. He entered the hospital April 11, 1913, to have his metabolism determined; at that time he was well-developed and well-nourished with a moderate amount of subcutaneous fat and strong muscles. The physical examination was normal except for an enlarged spleen which could be felt 3 cm. below the edge of the ribs; this was believed to indicate syphilis. His temperature was normal. At birth he weighed 0.45 kilogram less than the average infant; when he entered the hospital he weighed 4.50 kilograms or about 1 kilogram less than the average infant of the same age (3 months). His digestion was normal and except for the first few days, he gained weight consistently during his stay in the hospital, that is, after his food was strengthened from 100 to 120 calories per kilogram of body-weight.

Subject, K. R. Male; born December 6, 1912; birth-weight, 4.55 kilograms.

Previous to his coming to the hospital, he had always been fed on modified milk, but did not do well. He entered the hospital on April 2, 1913, at the age of 4 months. On physical examination he was found to be poorly developed, poorly nourished, and almost emaciated. He had a thin, pinched face, no subcutaneous fat, and the skin was rather loose. The muscles were small and fairly firm. He cried considerably and held his breath for periods as long as 45 seconds, during which he became distinctly blue, but there was no suggestion of a crow or of laryngismus stridulus. The physical examination was otherwise normal. The urine was also normal except that on one examination it showed a possible trace of albumen. This, however, was probably of no significance, as there were no other pathological signs. He was fed on a

mixture of cow's milk, relatively low in fat, which gave him about 120 calories per kilogram of body-weight. During his stay in the ward his digestion was apparently normal. His temperature was normal or subnormal. He was an undersized infant, whose digestion had been upset by over-feeding with fat. When he entered the hospital, his weight was 3.07 kilograms, which was less than his birth-weight. If he had developed in the ordinary way, he would have weighed about twice as much, the average weight for an infant of his age being 6.25 kilograms. When discharged from the hospital, he weighed 3.19 kilograms. His case was considered to be one of infantile atrophy.

Subject, A. S. Male; born at full term Dec. 26, 1912; birth-weight, 3.75 kg.

His history was unimportant, as he had always been breast-fed. When he entered the hospital on March 26, 1913, he was well developed and well nourished, with a normal amount of subcutaneous fat and firm muscles. He appeared strong and bright and held his head up without support. The physical examination was normal. During his stay in the hospital he was fed both breast and modified milk; his digestion was normal. It was necessary to puncture his ear drums on March 29 to relieve an acute otitis media, after which the temperature, which had previously been moderately elevated, dropped to normal. His weight remained stationary in the week he was under observation. He was a normal breast-fed infant, weighing approximately 6 kg. or about 0.5 kg. above the average weight for his age (3 months).

Subject, E. S. Female; born of healthy parents on October 13, 1912 (presumably premature at about 7 months); birth-weight, 1.93 kilograms.

She was breast-fed for 3 months but did not gain. She was then put on a diet of malted milk and later on a proprietary food, both of these being mixed with milk. While she did not vomit, she spit up her food occasionally, and had two brown stools a day which irritated the buttocks. When she entered the hospital on March 19, 1913, she had not gained weight recently. On physical examination she was found to be a poorly developed, thin infant, with an anxious expression. There was no subcutaneous fat, and the muscles were flabby. She appeared quiet but bright, and had a strong cry. The skin showed a dull redness, with macular papular eruption on the chin, joints, and buttocks. The physical examination was otherwise normal. She was fed on milk modified to her digestion, with a fuel value of about 140 calories per kilogram of body-weight; while under observation, her digestion was good. This infant was much under the average weight and also under the weight which she would have been had she gained consistently. With a history of prematurity and a birth-weight of 1.93 kilograms, it would be expected that at the age of 5 months (her age while in the hospital) she would weigh approximately 5.35 kilograms, whereas her average weight for this time was about 3 kilograms. The average weight for an infant of 5 months is 6.82 kilograms. She was, therefore, considerably under weight. Furthermore, the temperature during her entire stay was subnormal. She was accordingly considered to be a case of infantile atrophy.

Subject, E. H. S. Male; born at full term Aug. 28, 1913; birth-weight, 3.18 kg.

He had always been fed on modifications of cow's milk or on condensed milk, but did not thrive on any of the diets used. He had had symptoms of indigestion ever since birth and had lost weight, weighing when he entered the hospital on October 27, 1913, at the age of 2 months, only 2.4 kilograms. He was a poorly developed and nourished infant, with the expression of an old man. The face wrinkled when he cried, and the skin hung in folds on his arms and legs. The fontanelles and eyes were sunken; the skin was dry;

the hands and feet were cold. The physical examination was otherwise normal and the Wassermann reaction was negative. During a part of his stay in the hospital, it was impossible to give him the usual number of calories in his food, as, for instance, on November 24, when he received only 90 calories per kilogram of body-weight; the temperature at this time was subnormal, being 36.1° C. to 36.7° C. (97° F. to 98° F.). On November 13 and 21, when he received about 130 calories and 145 calories respectively, the temperature was normal. When he was discharged on December 27, 1913, he weighed 3.05 kilograms. His case was diagnosed as infantile atrophy. He weighed when 2 months old 0.8 kilogram less than at birth. His digestion was very weak.

Subject, G. S. Male; born December 1, 1912; birth-weight, 3.64 kilograms.

Since his birth he had been fed on various home modifications of milk, barley water, lime water, and milk sugar. He seemed hungry, cried considerably, and did not gain in weight. When he entered the hospital February 12, 1913, he was found on physical examination to be a well-developed but poorly nourished infant, with a small amount of subcutaneous fat. He appeared bright and active and had a strong cry. His weight was the same as at birth, whereas at his age (2½ months) it should have been 1.5 kilograms more. He was given milk modified to his digestion, with a fuel value of about 100 calories per kilogram of body-weight. Digestion not remarkable. His temperature remained normal. He was considered to be a case of regulation of feeding.

Subject, J. S. Male; born December 28, 1912; birth-weight, 5 kilograms.

For the first 6 weeks he was breast-fed; subsequently he was given a modification of cow's milk, but vomited after each feeding, cried most of the time, and was very constipated and hungry. He entered the hospital on June 3, 1913, at the age of 5 months. On examination he was found to be a small, emaciated infant, with the facies of old age. There was no subcutaneous fat and the skin hung in folds. The muscles were strong but firm. There was a slight rosary, but the physical examination was otherwise normal. He was given modified milk, with a fuel value of approximately 120 to 140 calories per kilogram of body-weight. The temperature was normal during his stay in the hospital. He was an atrophic infant with no definite signs of indigestion. His weight on entering the hospital was 4.08 kilograms and on his discharge 4.53 kilograms. This was less than his birth-weight and only half what he should have weighed at his age.

Subject, P. S. Male; born December 23, 1912; birth-weight unknown.

He had never been a well infant. On September 20, 1913, he had acute bronchitis. He entered the hospital on November 19, 1913, and had bronchopneumonia on November 21. Later he had otitis media. In the week preceding the determination of his metabolism, his temperature had been normal and he had gained in weight, although previous to that time he had lost considerable weight. His digestion was also good, and his physical examination was normal. His weight on December 18 was 7 kilograms, this being about 2 kilograms under weight, as the average weight for an infant of his age (12 months) is 9.5 kilograms.

Subject, H. T. Male; born October 25, 1912; birth-weight unknown.

This infant was breast-fed from birth and had always been healthy. He was brought to the hospital for weaning and taken into the ward on April 15, 1913, to have his metabolism determined. The physical examination was normal, showing that he was a strong, well-developed and well-nourished infant, with a large amount of subcutaneous fat. During his stay in the hos-

pital he received both breast milk and modified milk. His digestion and temperature were normal. He weighed about 2 kilograms more than the average infant of the same age ($5\frac{1}{2}$ months), his weight remaining stationary at 9.28 kilograms while he was in the hospital.

Subject, J. V. Female; born prematurely at 8 months on October 10, 1912, of a syphilitic mother; birth-weight, 1.45 kilograms.

She lost weight until at the end of the first week she weighed only 1.30 kilograms. For the first 4 weeks she was fed on human milk; she was then discharged from the Boston Lying-in Hospital to the Massachusetts General Hospital, which she entered on December 13, 1912. At this time she was a moderately nourished, poorly developed infant, about 45 cm. long. She cried lustily and took her food with a Breck feeder without help. A diagnosis of congenital syphilis was made by the skin department of the hospital before she entered the Children's Ward. From December 25 onward, she was given inunctions of mercury, one-half strength, until her discharge from the hospital.

On December 15, two days after her entrance, the temperature became elevated and remained so until the 20th, when it was found that she had an acute otitis media. After paracentesis, the temperature dropped to normal and remained there for several weeks. On March 11, the temperature again became elevated and 2 days later it was found that the infant had measles. The temperature remained elevated 7 days. She was allowed out of quarantine on March 27. On March 31 she again had acute otitis media, which was relieved by paracentesis. The ears continued to discharge until April 10; two days later paracentesis was once more necessary and there were symptoms of adenoid obstruction. On April 17, the adenoids were removed under ether, thus relieving the obstruction. After this the infant ate, acted, and looked better. On April 20 it was noted that there was marked craniotabes, a moderate rosary, a liver which could be felt 4 cm. below the edge of the ribs, and a spleen 3 cm. below the ribs. The ears stopped discharging shortly after the adenoids were removed and the general condition was much improved. On May 12, the record was made that she "laughed out loud."

She was fed on increasing strengths of modified milk. Her digestion was weak during most of her stay in the hospital. The weights recorded were as follows: October 10, 1912 (birth-weight), 1.45 kilograms; December 14, 1.84 kilograms; January 1, 1913, 1.84 kilograms; January 15, 1.92 kilograms; February 1, 2.05 kilograms; February 15, 2.22 kilograms; March 1, 2.50 kilograms; March 15, 2.70 kilograms; April 1, 3.10 kilograms; April 15, 3.00 kilograms, this being double her birth-weight; May 1, 3.10 kilograms; May 12, 3.33 kilograms. Although she doubled her birth-weight at 6 months, she weighed less than half the average weight of infants of the same age.

Subject, P. W. Male; born September 8, 1912; birth-weight unknown.

His family and past history were unimportant. He entered the surgical department of the hospital on March 26, 1913, because of acute retention of urine due to a horse hair tied tightly around the base of the penis. This was quickly relieved by removing the cause. His physical examination was normal. He was a healthy, well-developed infant, who acted normal in every way. During his stay the infant was given modified milk and digested it well. His food contained only about 85 calories per kilogram of body-weight, his weight remaining stationary at 7.10 kilograms. Since his birth-weight is unknown, it is impossible to calculate what his weight should have been for his age on that basis, but this weight is approximately the same as the average for his age. His temperature was normal and he could be considered a normal infant of average development.

CLINICAL STATUS OF INFANTS.

Table 22 summarizes the clinical status of each infant studied, and gives the age of the infant during the metabolism observations.

TABLE 22.—*Clinical status of infants studied.*

Name.	Age during metabolism observation.	Clinical status.
F. B.	5½ months.	Convalescent stage infantile atrophy.
M. A.	9 months.	Under weight, splenic tumor, with anemia.
J. B.	5 months.	Congenital syphilis, convalescent stage, infantile atrophy.
L. B.	4 months.	Under weight.
L. R. B.	4–4½ months.	Normal infant.
A. C.	1½ months.	Slightly under weight.
M. C.	4 months.	Normal infant or slightly under weight.
A. D.	4–5 months.	Convalescent stage, infantile atrophy.
M. D.	2–3 weeks.	Normal infant.
R. E.	4½ months.	Under weight or slightly under expected weight.
E. F.	3 months.	Normal infant.
E. G.	10 months.	Normal infant.
E. K.	17 months.	Much under weight; rachitis, recovering from broncho-pneumonia.
F. K.	7 months.	Under weight.
A. L.	3½–4 months.	Under weight.
E. L.	4 months.	Under weight, otitis media.
R. L.	6½–9 months.	Approximately normal; later, under weight.
D. M.	11 months.	Much under-weight, rachitis.
F. M.	4–5 months.	Under weight, congenital syphilis.
J. M.	8 months.	Under weight, otitis media, rachitis.
M. M.	4½ months.	Under weight following an acute indigestion.
E. N.	6½ months.	Under weight.
L. O.	5–6 months.	Infantile atrophy.
J. P.	6½–7 months.	Under weight, gaining weight rapidly.
W. P.	5–5½ months.	Under weight.
D. Q.	4½ months.	Under weight.
E. R.	3 months.	Under weight (slightly).
K. R.	4 months.	Infantile atrophy.
A. S.	3 months.	Normal infant, weighing more than the average.
E. S.	5 months.	Infantile atrophy.
E. H. S.	2½–4 months.	Infantile atrophy.
G. S.	2½ months.	Under weight.
J. S.	5–6 months.	Infantile atrophy ? (temperature not subnormal).
P. S.	12 months.	Under weight.
H. T.	5½ months.	Normal infant, weighing more than average.
J. V.	3½–9 months.	Prematurity; congenital syphilis; infantile atrophy in subnormal temperature, and convalescent stage.
P. W.	7 months.	Normal infant.

RESULTS OF OBSERVATIONS ON THE GASEOUS EXCHANGE.

With an investigation extending over so many months and dealing with so many subjects as were used in this research, it is obviously impracticable to present protocols for each observation. On the other hand, as the carbon-dioxide production, oxygen consumption, pulse-rate, and muscular activity were accurately recorded in each experimental period, it seemed desirable to present the data in permanent form. This is done in table 23.

Accordingly, the carbon-dioxide production per hour, respiratory quotient, average pulse-rate, and the estimated activity are given for

all of the observations and one line of the table is assigned for each experimental period. The arrangement by subjects is arbitrarily alphabetical, the observations with each infant being recorded in chronological order. Additional information is given as to the sex, age, and body-weight without clothing for the infants included in the study. While the carbon-dioxide production has been calculated on an hour basis, the actual length of the periods is also given, and the carbon-dioxide production for the individual periods may be readily calculated. No period is included which was less than 10 minutes in length. The results for the preliminary period of nearly all of the observations are given, usually appearing in the first line of the data, but as these are not used either in securing the average minimum metabolism,[1] or in computing the respiratory quotient, the experimental periods are bracketed to indicate this. No time is given for the observations, as the experiments were almost without exception carried out in the afternoon. The relation between the times of the observation and of the last feeding is recorded in the footnotes of the table; when this is not indicated, the feeding was invariably within 3 hours of the time when the infant was placed in the apparatus. Usually the preliminary period ended about 1 to 1½ hours after feeding. A key to the designations of the relative activity is placed at the head of the table. A full explanation of this method of estimating the activity may be found on p. 136.

TABLE 23.—*Results of observations on the gaseous exchange of infants.*

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*M. A., male, 9 mos.*	*mins.*	*gm.*			
Nov. 12	5.70 kilos..........	20½	5.71	....	117	V
		30	4.66	0.81	103	III
		30	5.04		103	III
		30	4.64		101	III
		42	5.01		104	IV
Nov. 14	5.63 kilos.........	71	5.97	....	125	VI
		30	4.68	0.79	105	II
		30	4.96		101	III
		22	5.65		113	VI
Nov. 17	5.80 kilos.........	25½	6.45	....	118	IV
		30	5.90	0.88	114	III
		30	5.96		116	IV
		23	5.66		110	IV
		22	5.29		110	III

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*M. A.* (cont.).	*mins.*	*gm.*			
Nov. 17[2]	5.73 kilos	35	5.45	....	123	VI
		35	4.87	0.80	103	II
		30	5.00		108	III
Nov. 18[3]	5.50 kilos..........	26	5.28	....	125	VI
		29	4.86		116	V
		30	5.30	0.78	118	IV
		25	5.69		134	VI
Nov. 18[4]	5.48 kilos.........	17	4.73	....	117	IV
		27	4.64		110	III
		30	5.00	0.73	114	III
		34	5.49		118	V
	F. B., male, 5½ mos.					
Apr. 23	4.75 kilos..........	10	7.38	....	127	IV
		30	5.44		112	II
		20	7.68		122	III
		30	5.42	0.87	112	II
		30	5.74		117	II
		29	5.50		107	II
Apr 24[5]	4.83 kilos..........	11	7.47	....	123	IV
		28	5.19		112	II
		29	5.15		117	III
		22	4.80	0.85	107	I
		23	5.22		114	I
		30	6.74		138	VI
Apr. 25	4.75 kilos..........	14	6.69	....	118	III
		20	5.58		111	II
		30	6.14		116	III
		18	5.30	0.86	107	III
		20	6.27		113	IV
		25½	5.11		101	II
Apr. 29	5.15 kilos..........	14	5.91	....	126	II
		23	5.79		119	I
		25	6.07		121	III
		24	5.88	0.88	114	III
		22	6.41		116	IV
		25	5.38		108	II
	J. B., male, 5 mos.					
Mar. 15	3.23 kilos	11	3.71	....	109	II
		41	3.95		113	IV
		27	3.76	0.94	103	II
		21	2.94		94	II
		15	4.08	....	102 ?	III

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 6 hours previous to these observations.

[3]Last feeding was about 20 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[4]Last feeding was about 25 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[5]Last feeding was about 7 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. B.* (cont.).	*mins.*	*gm.*			
Mar. 17	3.23 kilos	12	5.35	....	96	II
		30	3.88		97	II
		21	4.14	0.96	106	IV
		26½	3.35		87	I
		20½	4.10		...	IV
	L. B., female, 4 mos.					
Feb. 1	4.06 kilos	12	5.85	....	135	V
		30	3.80		127	II
		30	4.14		133	I
		30	3.84	0.84	123	I
		30	3.90		122	I
		30	3.84		120	III
Feb. 3	....	10	6.00	....	139	IV
		30	4.00		127	II
		37	5.04	0.91	133	V
		18	4.33		125	IV
Feb. 4	4.04 kilos...........	30	4.24	....	121	IV
		17	4.76	....	127	V
		17	5.96	....	130	VI
Feb. 5	4.01 kilos...........	13	4.94	....	135	V
		30	4.08		121	III
		27	5.40	0.92	138	V
		19	5.34		136	VI
		14	5.61	....	127	V
		30	4.22		119	II
		30	4.04	0.95	121	III
		30	4.12		117	III
	L. R. B., female, 4 mos.					
Nov. 1	6.08 kilos...........	17	6.28	....	...	V
		27	4.64		...	III
		55	6.08	0.80	...	VI
		30	4.30		...	III
Nov. 3	6.05 kilos...........	30	4.62	0.85	...	II
		50	6.14		...	VI
Nov. 3[2]	5.93 kilos...........	23	6.68	....	137	VI
		23	4.36		106	III
		26	4.18	0.77	113	IV
		30	4.20		107	I
Nov. 4[3]	5.95 kilos..........	29	4.12		102	II
		30	4.52	0.73	110	II
		29	4.14		103	III
Nov. 4[4]	5.95 kilos..........	51	5.96	....	...	VI
		29	4.39	0.74	...	II
		35	5.54		124	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 4½ hours before these observations, sterile water being given in place of food at the next time of feeding.

[3]Last feeding was about 19½ hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[4]Last feeding was about 24 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*L. R. B.* (cont.), *4½ mos.*	*mins.*	*gm.*			
Nov. 5	6.00 kilos..........	28	6.43	....	126	VI
		30	4.70		105	III
		22	5.73	0.83	119	V
		30	4.70		106	II
		22	4.96		110	III
	A. C., female, 1½ mos.					
Mar. 19	3.00 kilos..........	10	3.48	....	138	IV
		30	2.20		120	I
		27	2.49	0.84	129	III
		29½	2.24		119	II
		30½	2.81		132	IV
Mar. 20	3.02 kilos..........	26	3.35	....	142	III
		30	2.40		131	II
		24	2.53	0.93	128	II
		27½	2.23		120	II
Mar. 24	2.95 kilos..........	32	2.94	....	139	III
		30	2.48		131	I
		30	2.84	0.88	141	III
		27	2.64		132	II
		25	3.02		136	III
1914.	*M. C., female, 4 mos.*					
Jan. 1	6.05 kilos..........	16½	6.23	....	119	VI
		25	4.42		99	II
		26	4.78	0.84	109	II
		37	4.52		107	II
		20	6.09		124	VI
Jan. 2	6.20 kilos..........	29	5.54	....	121	V
		23	5.22		102	II
		23	4.67	0.88	102	III
		30	5.98		122	VI
Jan. 3	6.25 kilos..........	24½	6.56	....	124	VI
		26	4.82		99	II
		22	5.84	0.85	107	V
		31	5.13		103	II
Jan. 5	6.03 kilos..........	43½	6.30	....	136	VI
		25	4.75	0.90	121	IV
	A. D., female, 4 mos.					
Apr. 28	2.65 kilos..........	46	4.43	....	128	V
		84	3.94	0.83	126	V
May 8[2]	2.95 kilos..........	20	3.27		112	III
		23	3.34		121	III
		24	3.00		110	I
		22	2.75	0.89	106	II
		30	2.86		106	II
		20	2.76		99	II
		20	4.71		146	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 7 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*A.D.* (cont.), 4½ *mos.*	*mins.*	*gm.*			
May 12	3.01 kilos..........	14	4.54	....	127	I
		30	4.20	0.90	131	III
		32	4.18		131	II
		30	3.56		116	I
		33	3.71		123	II
May 15[2]	3.20 kilos..........	21	5.14	....	143	V
		30	3.80	0.94	124	III
		29	3.37		111	II
		19	3.98		123	IV
		28	5.74		154	VI
May 19[3]	3.23 kilos..........	14	3.13	....	115	I
		30	3.10	0.77	120	II
		25	3.02		113	I
		31	3.12		117	III
		23	2.66		104	I
		30	3.74		128	V
	A. D. (cont.), 5 *mos.*					
May 24	3.43 kilos..........	31	5.83	....	137	V
		24	4.28	0.92	118	III
		30	4.30		127	II
		26	3.60		113	I
		30	3.92		124	III
	M. D., male, 2 weeks.					
Mar. 8	4.08 kilos..........	19	3.95	....	150	IV
		30	3.14	0.86	136	IV
		30	4.64		152	V
Mar. 10	3.97 kilos..........	17	3.67	....	145	IV
		21	3.00	0.80	144	III
		30	2.92		140	III
		30	3.00		140	III
		30	2.86		135	II
		25	2.74		131	III
Mar. 11	4.00 kilos..........	30	2.90	0.84	133	IV
		30	2.66		129	III
		30	2.88		123	III
		30	2.60		121	II
		20	3.99		137	IV
	M. D. (cont.), 3 *weeks.*					
Mar. 14	4.00 kilos..........	22	3.08	0.83	128	IV
		37	3.47		132	V
		24	4.15		149	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 3 hours before these observations, sterile water being given in place of food at the time of feeding preceding these observations.

[3]Last feeding was about 21 hours previous to these observations. Sterile water was substituted at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*R. E., male, 4½ mos.*	*mins.*	*gm.*			
Dec. 4	5.10 kilos..........	41	6.64	....	129	VI
		24	4.55		114	IV
		23	4.70	0.83	118	II
		21	6.14		137	V
Dec. 4[2]	5.03 kilos..........	46½	5.89	....	141	VI
		22	4.45		121	III
		32	4.22	0.82	115	III
		29	4.04		117	IV
Dec. 5[3]	5.00 kilos..........	16½	4.22	....	106	III
		30	3.92		109	II
		24	4.08	0.74	115	II
		30	3.90		114	II
		30	5.18		137	V
Dec. 5[4]	4.95 kilos..........	15	4.36	....	119	III
		29	3.68	0.72	119	III
		111	6.46		141	VI
Dec. 9	5.03 kilos..........	19	5.94	....	133	V
		31	4.63		114	III
		33	4.36	0.74	115	II
		31	5.54		131	VI
Dec. 12	5.00 kilos..........	73	7.61	....	140	VI
		26	4.32	0.99	113	IV
	E. F., male, 3 mos.					
Dec. 2	7.05 kilos..........	18½	8.98	....	146	VI
		31	4.20	0.81	109	II
		26	8.45		140	VI
Dec. 3	7.08 kilos..........	32½	9.32	....	140	VI
		25	4.70	0.89	113	III
		24	8.78		137	VI
	E. G., male, 10 mos.					
Nov. 26	9.43 kilos..........	15½	6.77	....	112	II
		31	6.70		119	V
		23	6.63		115	IV
		23	5.97	0.72	111	II
		30	6.78		120	II
		30	8.44		133	VI
Nov. 27	9.45 kilos..........	47½	7.71	....	116	VI
		32	6.36	0.76	109	II
		19½	6.74		115	IV

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 6 hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[3]Last feeding was about 18½ hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

[4]Last feeding was about 24 hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*E. G.* (cont.)	*mins.*	*gm.*			
Nov. 27[2]	9.45 kilos...........	18	6.77	....	105	I
		30	5.76		98	I
		28	6.11	0.71	104	II
		30	5.94		100	IV
Nov. 28[3]	9.13 kilos...........	17½	6.58	....	111	III
		25	6.70		115	V
		26	6.81	0.72	113	IV
		30	5.94		108	II
		25	7.87		137	VI
Nov. 28[4]	9.20 kilos...........	34	7.13	....	115	V
		31	6.46		112	IV
		32	6.11	0.70	110	III
		21	6.03		112	IV
		26	7.75		126	VI
	E. K., male, 17 mos.					
Dec. 16	8.03 kilos...........	72	7.84	....	116	V
		29	6.70	0.80	105	II
		29	6.83		105	II
	F. K., male, 7 mos.					
May 2	5.68 kilos...........	22	7.45	....	138	VI
		16	6.34		121	IV
		22	5.40	0.84	109	I
		30	5.96		116	III
		30	7.58		141	V
May 3[5]	5.68 kilos...........	13	6.69	....	129	V
		20	5.13		109	I
		27	5.62	0.78	122	II
		20	8.94		168	VI
May 5[6]	5.70 kilos...........	14	7.24	....	128	V
		23	5.30		108	III
		32	5.64	0.84	118	III
		24	5.30		111	II
		20	6.78		136	V
May 6	5.70 kilos...........	19	7.39	....	136	VI
		20	5.73		112	II
		20	5.82		112	II
		23	6.37	0.89	119	IV
		21	5.71		109	III
		30	5.98		119	III

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 5½ hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[3]Last feeding was about 19½ hours previous to these observations. Sterile water was substituted in place of food at subsequent times of feeding.

[4]Last feeding was about 24½ hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[5]Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[6]Last feeding was about 6 hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*F. K.* (cont.)	*mins.*	*gm.*			
May 7[2]	5.75 kilos..........	14	7.11	....	133	V
		23	5.03		103	II
		19	5.49	0.78	113	III
		32	8.06		160	VI
May 9[3]	5.72 kilos..........	18	7.60	....	138	VI
		18	5.30		113	III
		21	4.89	0.77	105	II
		20	7.20		159	VI
	A. L., female, 3½ mos.					
June 14	3.10 kilos..........	21	5.11	....	136?	VI
June 16	3.10 kilos..........	60	4.82	....	127	VI
		15	4.28	0.89	110	I
		23	4.77		138	V
June 20	3.14 kilos..........	82	6.18	....	145	VI
		32	6.69	....	157	VI
June 23[4]	3.13 kilos..........	20	5.37	....	142	VI
		44	6.52	....	161	VI
June 24[4]	3.20 kilos..........	14	4.11	....	119	IV
		21	3.00	0.88	112	II
		24	4.45		133	VI
	A. L. (cont.), *4 mos.*					
June 28	3.15 kilos..........	42	4.73	....	118	V
		17	3.42	0.81	101	II
		22	5.21		125	VI
		36	5.17	....	137	VI
	E. L., male, 4 mos.					
May 17	4.15 kilos..........	12	5.75	....	136	III
		23	4.28		126	II
		24	4.98		134	III
		30	4.32	0.83	127	I
		30	4.90		130	III
		29	4.39		132	III
May 20	4.25 kilos..........	25	6.07	....	149	IV
		49	6.39	0.92	158	VI
May 21[5]	4.30 kilos..........	13	4.48	....	128	I
		47	6.87	0.93	159	VI
	R. L., male, 6½ mos.					
Mar. 3	8.10 kilos..........	30	6.20		112	II
		30	6.54	0.87	117	II
		30	6.84		121	III
		30	6.66		126	II

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 9 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[3]Last feeding was about 21 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[4]On June 23 and 24 the last feeding was about 3 hours previous to the observations, sterile water being given in place of food at the next time of feeding.

[5]Last feeding was about 3 hours previous to these observations. Sterile water being given in the place of food at the next time of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*R. L.* (cont.)	*mins.*	*gm.*			
Mar. 4	8.09 kilos..........	22	9.38	....	138	V
		30	7.62	0.87	129	IV
		30	6.84		128	III
		30	8.06		137	V
		30	7.20		130	III
Mar. 7	7.97 kilos..........	61	8.28	....	141	VI
	R. L. (cont.), *8½ mos.*					
Apr. 26	7.68 kilos..........	25	8.18	....	138	III
		20	7.65	0.88	137	II
		30	7.54		137	II
		26	7.75		149	IV
May 9	7.25 kilos..........	20	8.46	....	125	V
		21	6.89	0.89	119	IV
May 10	7.18 kilos..........	32	7.31	....	115	V
		26	5.91	0.81	105	II
May 13	7.25 kilos..........	40	8.30	....	131	VI
May 14[2]	7.25 kilos..........	15	7.96	....	119	IV
		20	6.78	0.86	110	II
		22	6.74		114	III
		22	7.06		107	IV
		30	6.90		107	III
		18	7.50		114	IV
May 16[3]	7.30 kilos..........	23	6.99	....	125	V
		20	5.64	0.74	110	II
		30	6.40		114	III
		26	5.93		110	III
		29	6.14		113	III
		28	5.66		111	IV
	D. M., *male, 11 mos.*					
Mar. 26	5.21 kilos..........	32	7.13	....	151	VI
		46	6.53	0.89	138	V
		22	5.43		123	III
		30	7.66		147	VI
Mar. 27	5.28 kilos..........	55	9.39	....	176	VI
Mar. 31	5.15 kilos..........	15	8.48	....	161	V
		30	6.26	0.84	140	III
		30	6.04		132	III
		15	5.48		121	III
		26	5.77		127	IV
		30	5.24		115	II
		17	5.75		120	III

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 3 hours previous to these observations, sterile water being given in place of food at the next time of feeding.

[3]Last feeding was about 21 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*F. M., male, 4 mos.*	*mins.*	*gm.*			
Jan. 22	3.57 kilos..........	36	7.37	....	140	VI
		26	4.75	0.89	127	IV
		30	5.06		127	V
		49	4.27		118	III
		30	4.48		116	II
Jan. 23	3.52 kilos..........	77	7.27	....	152	VI
		30	4.02	0.86	119	II
		30	4.46		123	II
		30	4.00		116	I
	F. M. (cont.), *5 mos.*					
Feb. 20	3.86 kilos..........	57	7.53	....	147	VI
		27	7.40	....	141	VI
		30	4.86	0.83	119	III
		30	4.70		118	II
	J. M., male, 8 mos.					
Apr. 2	5.54 kilos..........	30	6.82	0.87	121	II
		23	7.25		122	II
		24	7.63		125	IV
		20	7.02		119	III
		13	8.35		132	IV
		25	6.94		115	II
Apr. 4	5.72 kilos..........	10	8.70	....	132	V
		25	7.08	0.89	112	I
		30	7.40		113	III
		23	7.38		111	IV
		18	6.70		102	II
		30	7.34		112	IV
		16	6.41		97	I
		20	8.49		115	VI
	M. M., female, 4 mos.					
June 2	5.43 kilos..........	20	5.91	....	113	V
		23	4.38	....	95	I
		22	4.58	....	101	III
		24	6.18	....	118	VI
June 3[2]	5.46 kilos..........	27	4.00	0.87	96	II
		25	4.34		99	II
		30	4.28		96	II
June 5[3]	5.55 kilos..........	28	4.84	....	107	V
		30	3.66	0.77	93	I
		21	4.06		96	III
		27	3.80		90	II
		25	4.85		113	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[3]Last feeding was about 9 hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*M. M.* (cont.).	*mins.*	*gm.*			
June 7[2]	5.40 kilos..........	16	4.95	....	111	VI
		28	3.62		98	I
		19	4.52		104	IV
		30	3.64	0.74	96	II
		30	3.64		99	II
		20	5.46		127	VI
	E. N., female, 6 mos.					
May 21	5.40 kilos..........	52	9.10	....	150	VI
		19	7.36		134	VI
		20	4.98	0.90	109	I
		20	5.52		121	II
May 22[3]	5.40 kilos..........	23	5.48		119	II
		23	5.40		117	I
		20	5.49	0.92	112	I
		32	5.42		115	I
		20	6.99		139	V
May 23[4]	5.41 kilos..........	72	7.83	....	152	VI
		19	4.52		109	I
		22	5.07	0.80	116	I
		20	4.56		106	I
		20	5.10		124	I
May 26[2]	5.25 kilos..........	15	6.16	....	126	IV
		20	4.50		104	I
		30	4.82	0.78	112	I
		30	4.84		113	I
		31	5.81		140	V
May 28[4]	5.38 kilos..........	20	5.55	....	118	III
		25	4.92		106	I
		21	5.09		111	I
		22	5.10	0.86	103	I
		25	5.21		110	II
		23	4.62		105	I
May 29[5]	5.45 kilos..........	14	5.79	....	124	III
		27	5.31		116	II
		30	5.54	0.88	116	II
		27	5.82		115	III
		20	5.40		110	III
	E. N. (cont.) *6½ mos.*					
May 31[3]	5.48 kilos..........	18	6.97	....	117	III
		25	5.33		104	I
		24	5.65	0.90	114	II
		23	5.19		105	I
		20	6.78		130	V

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 21 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[3]Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[4]Last feeding was about 9 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[5]Last feeding was about 4 hours before these observations, sterile water being given in place of food at the next time of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*L. O., male, 5 mos.*	*mins.*	*gm.*			
Feb. 10	2.99 kilos..........	32	3.60	....	106	III
		30	3.88	....	105	IV
		30	3.98	....	110	IV
		30	3.92	....	109	IV
Feb. 12	2.98 kilos..........	30	3.82	....	110	III
		19	3.98	....	102	III
		30	4.14	....	109	IV
		30	4.20	....	113	IV
	L. O. (cont.), $5\frac{1}{2}$ *mos.*					
Feb. 18	3.05 kilos..........	30	4.00		119	III
		30	3.90	0.88	114	III
		30	4.08		121	IV
		30	3.86		115	IV
Feb. 24	3.18 kilos..........	10	4.80	....	110	V
		20	4.35		113	IV
		22	3.63		99	II
		30	4.12	0.87	111	III
		30	3.86		103	III
		30	3.94		103	II
Feb. 25	3.15 kilos..........	12	5.85	....	116	V
		30	4.28		111	IV
		30	4.22		107	II
		30	3.84	0.90[2]	100	III
		30	4.04		104	V
		30	4.18		111	IV
Feb. 28	3.12 kilos..........	30	4.06		112	III
		30	4.06		103	II
		30	3.90	0.95	102	II
		25	4.20		125	VI
		30	4.30		119	IV
Mar. 1	3.15 kilos..........	11	4.42	....	111	IV
		30	4.00		105	III
		30	4.06		107	II
		30	3.58	0.97	93	I
		30	4.12		107	V
		30	4.32		105	IV
	L. O. (cont.), *6 mos.*					
Mar. 7	3.31 kilos..........	10	5.52	....	121	VI
		30	4.04	0.96	109	III
		22	4.25		115	V
Mar. 12	3.31 kilos..........	30	4.30		123	II
		20	4.74		129	III
		30	4.52	0.89	130	IV
		23	4.62		122	III
		30	5.14		138	V

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.
[2]Determined for the time included in the first two and the last two periods.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. P., male, 6½ mos.*	*mins.*	*gm.*			
Oct. 31	5.40 kilos	40	7.71	....	140	VI
		30	5.84	0.87	...	II
		30	6.40		...	III
		29	5.52		...	III
		19	6.41		113	IV
Nov. 6	5.60 kilos	25	6.72	0.89	114	IV
		48	6.26		112	IV
		33	6.45		110	V
Nov. 7	5.65 kilos	13	7.11	....	121	IV
		30	6.48	0.91	102	I
		30	6.14		103	II
		35	6.29		107	IV
		30	5.54		106	II
Nov. 10	5.55 kilos	16½	6.91	....	115	V
		30	6.40	0.89	105	IV
		30	6.06		104	IV
		30	6.18		107	III
		30	6.16		106	IV
Nov. 10[2]	5.40 kilos	88½	7.05	....	126	VI
		30	5.00	0.86	102	III
		30	5.52		108	III
Nov. 11[3]	5.35 kilos	20	5.82	....	119	V
		30	5.06	0.79	106	II
		28	5.36		110	IV
		20	5.55		108	IV
	J. P. (cont.), *7 mos.*					
Nov. 11[4]	5.30 kilos	19½	5.63	....	129	V
		35	5.34	0.73	112	V
		32	6.06		117	VI
		23	4.96		107	IV
	W. P., male, 5 mos.					
Jan. 27	4.31 kilos	15	6.92	....	143	VI
		30	6.26	0.88	134	V
		30	5.16		120	IV
		30	6.12		130	V
Jan. 29	4.26 kilos	15	7.32	....	138	VI
		16	5.81	0.86	122	VI
		23	5.95		121	VI
		27½	4.41		99	III
		12½	5.76		115	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 5½ hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[3]Last feeding was about 19 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

[4]Last feeding was about 24½ hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*W. P.* (cont.).	*mins.*	*gm.*			
Jan. 30	4.28 kilos..........	26	5.58	....	117	VI
		30	4.84		96	II
		30	4.70		95	III
		30	4.46	0.92	94	III
		30	4.60		97	II
		19	4.89		109	IV
Jan. 31	4.34 kilos..........	12	5.65	....	120	VI
		30	4.46		95	I
		30	4.78		102	III
		30	4.64	0.92	98	III
		30	4.36		96	II
		17	5.26		106	V
	W. P. (cont.), *5½ mos.*					
Feb. 11	4.57 kilos..........	36	7.02	....	135	VI
	D. Q., male, 4½ mos.					
Dec. 22	5.20 kilos..........	30	8.93	....	142	VI
		29	4.03	0.89	97	III
Dec. 23	5.35 kilos..........	26	7.13	....	130	VI
		30	4.48		106	I
		30	4.54	0.81	102	II
		30	4.06		98	II
	E. R., male, 3 mos.					
Apr. 11	4.59 kilos..........	16	5.44	....	139	V
		21	4.23		129	III
		33	4.62	0.83	133	IV
		57	4.38		130	IV
		17	4.16		126	V
Apr. 12	4.49 kilos..........	17	7.06	....	151	VI
		21	4.26		124	IV
		63	6.10	0.73	146	VI
		23	4.80		131	V
		24	3.58		122	II
Apr. 14	4.49 kilos..........	12	4.75	....	131	VI
		27	4.11		119	III
		31	4.32		124	IV
		22	4.50	0.86	124	II
		34	4.15		123	IV
		20	4.14		119	I
Apr. 15[2]	4.49 kilos..........	14	4.84	....	120	VI
		20	4.02		113	IV
		26	3.72		110	III
		25	3.67	0.80	114	III
		26	3.90		110	II
		30	3.94		117	IV
		21	3.37		106	II

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.
[2]Last feeding was about 3 hours previous to these observations, sterile water being given in place of food at the next time of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*K. R., male, 4 mos.*	*mins.*	*gm.*			
Apr. 5	3.14 kilos...........	78	4.51	....	116	VI
		23	2.74	0.83	91	II
		40	5.33		140	VI
Apr. 7	3.19 kilos...........	10	5.16	....	116	V
		30	3.20	0.88	107	I
		30	3.44		108	III
		27	3.31		108	II
		30	3.44		115	III
		26	3.14		106	II
	A. S., male, 3 mos.					
Mar. 28	6.04 kilos...........	11	9.00	....	143	V
		117	6.12	0.92	142 ?	VI
Mar. 29	6.10 kilos...........	37	8.51	....	...	VI
Apr. 1	6.02 kilos...........	16	4.73	0.81	117	IV
		23½	4.19		113	II
	E. S., female, 5 mos.					
Mar. 21	2.95 kilos...........	17	4.98	....	126	VI
		30	3.78	0.94	112	IV
		30	3.36		115	I
		30	3.30		107	III
		30	3.82		114	V
Mar. 22	3.00 kilos...........	13	4.29	....	99	V
		26	3.25	0.95	101	III
		20	4.11		114	IV
		30	3.34		98	I
		30	3.30		92	I
Mar. 25	3.03 kilos...........	19	4.52	....	119	V
		30	3.66	0.91	112	II
		30	3.56		115	III
		30	3.52		110	III
		30	3.34		100	III
	E.H.S., male, 2½ mos.					
Nov. 13	2.85 kilos...........	17½	3.98	....	123	V
		38	3.43	0.90	116	V
		30	2.64		103	II
		30	2.88		108	IV
		33	3.38		121	VI
Nov. 21	2.85 kilos...........	17	2.68	....	114	III
		48	2.75	0.77	116	V
		34	2.51		113	II
		41	2.33		109	III
		24	3.00		123	V
	E. H. S. (cont.), 3 mos.					
Dec. 1	2.88 kilos...........	40	2.93	....	83	V
		32	2.61	0.83	78	II
		25	3.12		91	IV
		33	3.05		89	IV
		32	3.69		109	V

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*E.H.S.* (cont), *3½ mos.*	*mins.*	*gm.*			
Dec. 17	3.08 kilos..........	17	3.60	....	122	III
		24	2.93		113	III
		39	4.42	0.97	127	VI
		31	3.25		113	II
	E. H. S. (cont.), *4 mos.*					
Dec. 29	3.15 kilos..........	18½	3.76	....	116	IV
		24	3.68		112	III
		24	3.20	0.92	103	I
		30	3.38		107	II
		34	4.38		119	VI
	G. S., male, 2½ mos.					
Feb. 13	3.24 kilos..........	18	4.20	....	131	VI
		23	3.16		122	III
		22	4.36	0.93	134	VI
		26	4.50		132	VI
Feb. 14	....	32	5.64	....	150	VI
		12	3.85		129	V
		20½	3.04		122	II
		30½	3.80	0.92	123	V
		30	3.36		116	III
		29	3.06		110	II
Feb. 17	3.33 kilos..........	19	5.81	....	152	VI
		26	3.42		124	IV
		30	3.50		125	III
		30	3.42	0.83	124	IV
		30	3.26		121	III
		30	3.02		117	II
Feb. 19	3.33 kilos..........	30	3.48		125	IV
		30	3.56		130	III
		30	3.50	0.88	123	III
		30	3.32		121	III
		30	3.24		118	IV
	J. S., male, 5 mos.					
June 6	4.20 kilos..........	18	4.47	....	99	IV
		50	5.12	0.95	108	V
		40	5.63	....	123	VI
June 11	4.10 kilos..........	16	5.03	....	107	V
		20	4.77	....	103	V
		29	4.16		100	II
		30	4.44	0.95	105	III
		30	5.84		123	VI
	J. S. (cont.) *5½ mos.*					
June 12	4.05 kilos..........	19	6.63	....	122	VI
		30	6.40	0.98	121	VI
June 17	4.35 kilos..........	15	5.76	....	118	V
		20	4.53		102	III
		30	4.86	0.97	99	I
		23	4.62		105	IV

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number, III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. S.* (cont.)	*mins.*	*gm.*			
June 18[2]	4.40 kilos...........	15	6.16	....	112	V
		23	4.23	....	95	II
		30	4.58	....	105	I
		22	4.72	....	111	IV
		30	8.18	....	161	VI
June 19[3]	4.51 kilos...........	41	8.63	....	183	VI
		15	5.40	....	123	II
		20	4.56	0.88	115	III
		30	5.02		128	II
June 21[3]	4.47 kilos...........	30	4.54	....	115	II
		15	5.72	....	117	II
		24	4.75	....	116	II
June 24	4.50 kilos...........	15	6.60	....	132	V
		27	6.38	0.95	...	V
June 26	4.55 kilos...........	33	7.22	....	140	VI
		23	5.63	0.96	115	I
		25	6.10		129	V
		27	6.22		122	IV
	J. S. (cont.), *6 mos.*					
June 27	4.53 kilos...........	21	5.51	0.97	111	I
		33	5.22		120	II
	P. S., male, 12 mos.					
Dec. 18	7.00 kilos...........	31	9.02	....	137	VI
		19	7.29	0.84	114	IV
		31	6.83		100	II
		31	6.48		103	II
Dec. 19	6.85 kilos...........	17	8.49	....	118	V
		30	6.24	0.84	101	II
		30	6.98		100	II
		23	6.16		95	II
		20	8.91		124	VI
Dec. 19[4]	6.78 kilos...........	43	6.81	....	112	V
		30	5.76	0.83	102	I
		30	6.56		108	III
Dec. 20[5]	6.80 kilos...........	37½	7.70	....	128	VI
		30	5.46	0.71	98	II
		30	6.00		98	II
Dec. 20[6]	6.58 kilos...........	21	6.68	....	109	V
		30	5.20	0.71	96	II
		61	7.43		121	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

[2]Last feeding was about 3 hours previous to these observations, sterile water being given in place of food at the next time of feeding.

[3]On June 19 and June 21 last feeding was about 6 hours before the observations. Sterile water was substituted for food at subsequent times of feeding.

[4]Last feeding was about 5½ hours before these observations. Sterile water was substituted for food at subsequent times of feeding.

[5]Last feeding was about 19½ hours previous to these observations. Sterile water was given in place of food at subsequent times of feeding.

[6]Last feeding was about 24½ hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*H. T., male, 5½ mos.*	*mins.*	*gm.*			
Apr. 16	9.28 kilos..........	68	11.12	....	126	VI
Apr. 17	9.33 kilos..........	10	5.82	....	101	II
		26	6.55	0.95	101	II
		16	7.01		117	IV
	J. V., female, 3½ mos.					
Jan. 15	1.92 kilos..........	30	2.42	....	146 ?	II
		30	2.52	0.89	145 ?	II
Jan. 16	....	14	3.47	....	136	II
		30	1.44	0.90	130	I
		30	3.58		150	VI
Jan. 17	....	16	2.89	....	122	II
		28	2.55	....	129	IV
		20	3.66	0.83	160	VI
Jan. 20	....	36	3.55	....	151	VI
		30	2.26	0.79	131	II
		60	2.26		129	II
Jan. 21	1.94 kilos..........	30	4.18	....	156	VI
Jan. 24	....	22	3.08	....	121	V
		65	2.78	0.88	132	V
		22½	2.80		132	V
Jan. 25	....	39	3.72	....	145	VI
		30	2.22	0.85	126	III
		30	3.04		143	V
	J. V. (cont.), *4 mos.*					
Jan. 28	....	34	3.67	....	147 ?	V
		11	4.53	0.94	160	VI
		30	4.16		166	VI
Feb. 11	2.10 kilos..........	20	3.18	....	147	V
		23	2.48	0.94	138	IV
		27	4.00		149	VI
	J. V. (cont.), *4½ mos.*					
Feb. 15	2.20 kilos..........	30	2.74	....	141	II
		30	2.86	....	140	II
		30	2.82	....	144	III
		30	3.04	....	137	IV
		27	3.09	....	139	IV
Feb. 26	2.45 kilos..........	18	4.07	....	143	V
		66	3.65		142	V
		30	3.60	0.91	139	V
		30	3.22		131	IV
		30	3.36		130	II
Feb. 27	2.45 kilos..........	28	3.96	....	143	VI
		38	3.65		144	V
		30	3.34	0.83	135	III
		26	3.58		141	V
		30	3.28		136	III

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. V.* (cont.), *5 mos.*	*mins.*	*gm.*			
Mar. 5	2.56 kilos..........	17	3.56	....	142	III
		35	3.67		147	IV
		31	4.03		156	IV
		31	4.35	0.92	152	IV
		30	3.68		143	III
		30	3.62		138	II
Mar. 6	2.58 kilos..........	16	4.43	....	147	IV
		20	3.69		147	III
		30	3.76		146	IV
		30	3.68	0.94	140	III
		30	3.76		137	III
		30	3.24		131	I
		20	3.81		133	IV
	J. V. (cont.), *5½ mos.*					
Mar. 13	2.73 kilos..........	14	4.46	....	168	IV
		25	3.91		156	III
		30	3.86	0.91	150	IV
		30	3.76		146	II
		30	3.58		141	II
Mar. 27	2.98 kilos..........	14	4.89	....	144	IV
		30	3.90	0.89	132	II
		30	4.08		134	III
Mar. 29	3.08 kilos..........	33	5.27	....	148	VI
		30	3.82	0.94	130	II
		29	3.87		129	III
	J. V. (cont.), *6 mos.*					
Apr. 8	3.17 kilos..........	45	4.13		145	V
		25	3.62		132	II
		20	4.17	0.82	134	IV
		22	3.68		130	III
		26	3.65		127	III
Apr. 9	3.17 kilos..........	12	4.40	....	144	I
		54	5.02	....	151	V
		52	5.30	....	159	VI
Apr. 10	3.17 kilos..........	69	4.79	....	148	VI
		22	3.74	0.84	137	III
		24	4.20		141	IV
Apr. 17	2.89 kilos..........	28½	3.43	0.79	123	V
		24½	3.45		124	IV
Apr. 18	2.98 kilos..........	10	3.60	....	130	I
		22	3.27		123	II
		18	3.63		128	III
		24	3.53	0.82	126	IV
		36	3.60		126	IV
		29	3.39		128	IV

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II, Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. V.* (cont.), $6\frac{1}{2}$ *mos.*	*mins.*	*gm.*			
Apr. 21[2]	2.98 kilos..........	52	4.26	....	133	VI
		26	3.55		123	III
		33	3.91		132	V
		28	3.75	0.79	126	III
		21	3.26		122	III
		21	3.43		123	III
Apr. 22[3]	2.93 kilos..........	24	4.53	....	136	V
		36	4.25		140	VI
		20	3.21		110	II
		26	3.39	0.81	115	III
		28	3.02		110	III
		30	3.24		114	III
Apr 30.	3.13 kilos..........	29	4.86	....	147	V
		20	3.78	0.85	127	III
		40	4.76		146	VI
		12	6.50	....	169	VI
	J. V. (cont.), 7 *mos.*					
May 1[4]	3.13 kilos..........	40	3.81	0.78	130	V
		10	3.96	....	135	IV
		29	3.91		134	V
		24	4.55	0.73	147	VI
		30	4.84		154	VI
	J. V. (cont.), $7\frac{1}{2}$ *mos.*					
May 27	3.25 kilos..........	17	5.51	....	138	V
		20	4.17		122	II
		30	4.52		122	III
		30	4.40	0.88	119	III
		24	4.03		118	II
		20	4.98		134	V
June 4	3.30 kilos..........	88	5.17	....	129	VI
		15	5.80	....	149	VI
	J. V. (cont.), 8 *mos.*					
June 9	3.50 kilos..........	40	5.79	....	145	VI
		11	4.69	....	131	II
		60	5.42	0.87	142	V
June 10	3.35 kilos..........	48	5.80	....	149	VI
		32	5.74	....	151	VI
June 12	3.35 kilos..........	16	5.48	....	137	IV
		19	4.58	0.94	129	II
		30	5.86		141	V
June 13	3.38 kilos..........	15	5.92	....	134	V
		23	4.43		123	III
		30	4.70	0.90	120	III
		47	5.67		136	VI

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table. 31, p. 142.

[2]Last feeding was about 3 hours previous to these observations, sterile water being substituted for food at the next time of feeding.

[3]Last feeding was about 6 hours before these observations. Sterile water was given in place of food at subsequent times of feeding.

[4]Last feeding was about 21 hours previous to these observations. Sterile water was substituted for food at subsequent times of feeding.

TABLE 23.—*Results of observations on the gaseous exchange of infants*—Continued.

[I, Very quiet, probably asleep; II. Slight movements, few in number; III, Some activity, but generally quiet; IV, Moderately active; V, Distinctly active; VI, Very active, most or all of the time.]

Date.	Sex, age, and weight without clothing.	Length of period.	Carbon dioxide produced per hour.[1]	Respiratory quotient.	Average pulse-rate.	Relative activity.
1913.	*J. V.* (cont.), *8½ mos.*	*mins.*	*gm.*			
June 25	3.40 kilos..........	17	5.29	....	130	V
		22	4.42		125	III
		25	4.70	0.88	124	III
		25	4.20		122	IV
		30	5.62		140	VI
June 30	3.39 kilos..........	17	5.15	....	142	IV
		26	4.59		135	IV
		22	4.36	0.92	129	III
		27	4.67		127	IV
		26	4.68		125	IV
	P. W., male, 7 mos.					
April 1	7.11 kilos..........	21	7.69	....	144	V
		14	7.54		130	IV
		10	7.20		134	V
		30	6.20	0.86	120	II
		30	6.40		121	III
		30	6.40		122	III
		30	6.54		125	IV
April 3	7.11 kilos..........	30	6.50		127	I
		28	5.89		117	I
		17	6.53	0.84	119	II
		23	6.13		115	II
		28	6.56		124	IV

[1]Calculated from the weight of carbon dioxide produced during the period. The preliminary periods for all days are omitted in computing the minimum metabolism. See table 31, p. 142.

While the data given in table 23 are made the basis of the discussion of our results in Part III of this publication, they may likewise be used for the discussion of many problems which have not been considered at this time. Furthermore, observations are still in progress in which supplementary evidence is rapidly being accumulated. Hence we wish it clearly understood that the data in table 23 are recorded here not only for present use, but for deferred discussion, in another place, of the many problems connected with the study of the metabolism of infants, such as the influence upon metabolism of crying, intense muscular activity, subnormal or febrile temperatures, and various distinctly pathological conditions.

PART III.

DISCUSSION OF RESULTS.

In a recent study of the metabolism of diabetics in this laboratory, it was found that the experiments were much lessened in value because of the lack of suitable normal controls. This led us to believe that our best service to pediatrics would be to determine the normal metabolism of infants. Accordingly, while a few observations were made with distinctly pathological cases, our data were secured for the most part with normal or under-weight infants.

One important problem in such an investigation is the relationship between muscular repose and metabolism. The graphic registering device for recording the muscular movements of the infant gave us an exceptionally good opportunity to obtain data regarding this relationship, which was made an object of special study in this investigation.

Furthermore there is a wide difference of opinion among physiologists as to whether or not during sleep there is a lowered metabolism, some writers maintaining that it is possible for a man to relax his muscles voluntarily so as to have a metabolism while awake as low as that during sleep, the sleep of itself having no influence upon the metabolism. With infants it is almost impossible to obtain periods of muscular repose while the infant is awake and it was recognized at once that only those periods when the infant was asleep could reasonably be looked upon as periods of complete muscular rest. It was hoped, however, that certain periods might throw light upon the effect of sleep upon metabolism.

The influence upon metabolism of the ingestion of food also received some attention in this research as an increased metabolism following the ingestion of protein, fat, or carbohydrate has been noted in many observations made with adults. This increase in the metabolism has been variously ascribed to the mechanical work of digestion, to the so-called specific dynamic action of the foodstuffs, or, as is now the belief in this laboratory, to the stimulating effect of certain substances—the specific katabolic stimuli—absorbed from the food material through the alimentary tract, and there carried by the blood to the cells to stimulate them to greater activity. Reasoning from the results obtained with adults, an infant receiving nutriment should have a greater metabolism than when he is without food; and it was hoped that experiments could be made with normal infants in which the influence of the ingestion of food could be more carefully studied. Difficulty was found at the outset in securing periods of quiet with infants under any conditions, but greater difficulty was had when the infants were not fed. Our experience, we admit, is very limited and we hope to profit by the suggestions of other observers, particularly Schlossmann and Murschhauser, in securing further aid in this important study. The data we have thus far obtained are somewhat fragmentary and by no means convincing; in fact, they hardly justify an extended discussion.

Our chief aim, therefore, was to study the metabolism of normal infants under conditions approximating the ideal, these infants to be selected, first, with varying ages; second, with varying weights; and third, of both sexes. That a sufficient number of observations could be made in one or two years to establish a standard for the normal metabolism of infants was hardly to be expected, but we at least hoped to make a good beginning, knowing that in subsequent years our data would be supplemented[1] and our findings from time to time revised.

Perhaps the most important abstract problem which is met with in an investigation of this nature—a problem interesting alike to both physiologists and pediatricians—is the cause of the variations in the metabolism of the infant. For instance, is the metabolism proportional to the active mass of protoplasmic tissue? There is clearly a suggested relationship between the metabolism and the body-weight, but the metabolism per kilogram of body-weight is by no means an index of the mass of active protoplasmic tissue; nevertheless some relationship should exist. At present we are wholly unable to determine the total mass of the active protoplasmic tissue in an infant's body. Unquestionably much of the gain in weight of a growing infant is due to the storage of fat; it is likewise certain that the gain in weight due to the nitrogen retained may not all be due to the formation of active protoplasmic tissue; thus the problem is doubly complicated.

We may further ask "Is the metabolism proportional to the body-surface?" Such a stimulating suggestion has been made by Rubner, who computed in his earlier experiments the relationship between body-surface and heat-production, finding it to be relatively constant for practically all species of warm-blooded animals, ranging in size from a horse to a mouse. In round numbers Rubner finds this relationship to be not far from 1,000 large calories per square meter of body-surface per 24 hours. To throw light upon the important physiological problem of the relationship between the body area and the total metabolism was one of our main problems.

PULSE-RATE.

Very little attention has been paid to the normal pulse-rate of infants, so that only such general statements as the following from Holt[2] are found in the text books:

"The pulse in early life is not only more frequent but it is very much more variable than in adults. The following is the average pulse-rate of healthy children during sleep or perfect quiet:

6 to 12 months, 105 to 115 per minute; 2 to 6 years, 90 to 105 per minute.

[1]As our page proof goes to press, we are informed that Hoobler and Murlin have very recently duplicated some of our experiments and although their observations include but two atrophic infants, they report that their findings are in full accord with ours. Their results were reported under the title "The energy metabolism of normal and marasmic children" at the fifty-eighth meeting of the Society for Experimental Biology and Medicine, in New York, April 15, 1914, and also at a meeting of the Inter-Urban Club, New York, April 17, 1914.

[2]Holt, Diseases of infancy and childhood, New York and London, 1911, p. 565.

"The pulse is a little more frequent in females than in males. Muscular exercise or excessive excitement increases the pulse-rate from 20 to 50 beats. Very trivial causes disturb not only the frequency but the force of the pulse."

Some figures are given in a few observations by Townsend,[1] which show that the pulse-rate of the crying baby is more rapid than that of the quiet baby, but no definite, continuous data have been reported other than the observations published by the writers in a previous paper.[2]

An examination of the records thus far given in this report shows that it is of the greatest moment whether the infant is asleep or awake when the pulse observations are taken. It is probable that most of the records of pulse-rate previously reported by observers have been made when the infants were awake and possibly more or less restless. But little data are available, therefore, as to the minimum pulse-rate and the length of time required for the pulse to reach the minimum after muscular activity.

PRELIMINARY OBSERVATIONS.

To secure more definite information on this subject, observations were made by one of us (F. B. T.) at the Boston Lying-in Hospital and the Directory for Wet Nurses at the Massachusetts Babies' Hospital, in which a stethoscope was attached directly to the infant. Records could thus be taken by skilled nurses without disturbing the subject. From this extended series, a few typical pulse curves have been selected for reproduction here, including two previously published in the paper referred to. These give a fair index of the fluctuations which would normally be expected with infants of different ages and varying activity.

The curve shown in figure 11 was obtained with S—ns at the age of 3 days, the records being taken practically every 5 minutes between $7^h\ 5^m$ p. m. and $6^h\ 28^m$ a. m. The maximum pulse-rate was 161 beats and the lowest observed value was 101 beats. When the curve is carefully examined, it will be seen that there was a general tendency for the pulse-rate to fall to a minimum of not far from 112 to 115, although the line is characterized by rapidly varying fluctuations.

The second curve (see figure 12) was obtained 5 days later with the same infant, and shows the general irregularities of the first. The maximum record is even higher, *i. e.*, 174, while the minimum is 108. During the latter part of the night, the minimum count was not far from 115 beats for several minutes.

A similar set of observations was made with Dow, 4 days old, covering the same period of time as those with the first infant (see figure 13). The maximum pulse-rate with this infant was 165 and the minimum

[1]Rotch, Pediatrics, 5th ed., 1907, Philadelphia and London, p. 67.

[2]Benedict and Talbot, Am. Journ. Diseases of Children, 1912, **4**, p. 129. Since this was written the valuable article by Katzenberger, Zeitschr. f. Kinderheilk., 1913, **9**, p. 167, entitled *Puls und Blutdruck bei gesunden Kindern*, has appeared.

110. On one or two occasions the pulse-rate seemingly approximated a minimum of 112 to 113.

With Weldon, 8 days old, the maximum was 161, and the minimum 111. Here again the curve, which is given in figure 14, is characterized by rapid and sudden fluctuations of considerable extent, although at times there is a tendency for the curve to reach a minimum of about 115.

With Herbert W., 5 weeks old, the pulse records were obtained throughout the night for a period of 12 hours and are given in figure 15. The maximum record was 134 and the minimum 98. Several times during the night, the pulse-rate reached a minimum of about 100.

Another 12-hour observation was obtained with Rita McL., 3 months old, giving a maximum pulse-rate of 140 and a minimum of 87 (see figure 16). A minimum average is shown at not far from 90.

Paul, 3 months old, in the same period of time had a maximum pulse-rate of 154 and a minimum of 97, with an average minimum of approximately 100. The curve is given in figure 17.

Tremballe, 5 months old, gave a maximum of 147 and a minimum of 83. During the latter part of the night, the minimum records showed an average of not far from 90 (see figure 18).

With Christine D., 7 months old, the maximum record was 139, while the minimum pulse-rate was 90, with the curve (figure 19) seeking an average minimum of 90 during the latter part of the night.

While all the curves indicate a quick reaction to muscular activity of any kind, it would appear that the younger the infant, the greater these fluctuations were and the more sensitive the infant was to changes in muscular activity. The average minimum record for infants 8 days old or under was approximately 115, while infants of 3 months or over showed an average minimum of about 90. After nursing, the pulse-rate was always high, but would subsequently reach its normal level in about 30 minutes if the infant remained quiet. Although the difference was not very great, the curves as a general rule show that the older the infant, the more rapid was the return to the average pulse-rate after nursing.

While the recent observations of Katzenberger[1] are of great importance in supplementing our previous scant knowledge regarding the average pulse-rate of infants and hence make any extensive comparison of our data on different infants entirely unnecessary, we believe that our observations show for the first time the large variations in pulse-rate of afebrile infants during the night when extraneous muscular activity is presumably less than during the day. We may correctly infer that the fluctuations in the pulse-rate shown in these records are probably exceeded by variations during the day and, consequently, in the ordinary daily life of infants we have to deal with very wide fluctuations in pulse-rate. Comparative data for different infants, to be of value, should therefore be obtained at the minimum. This can only be secured during deep sleep.

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[1]Katzenberger, *loc. cit.*

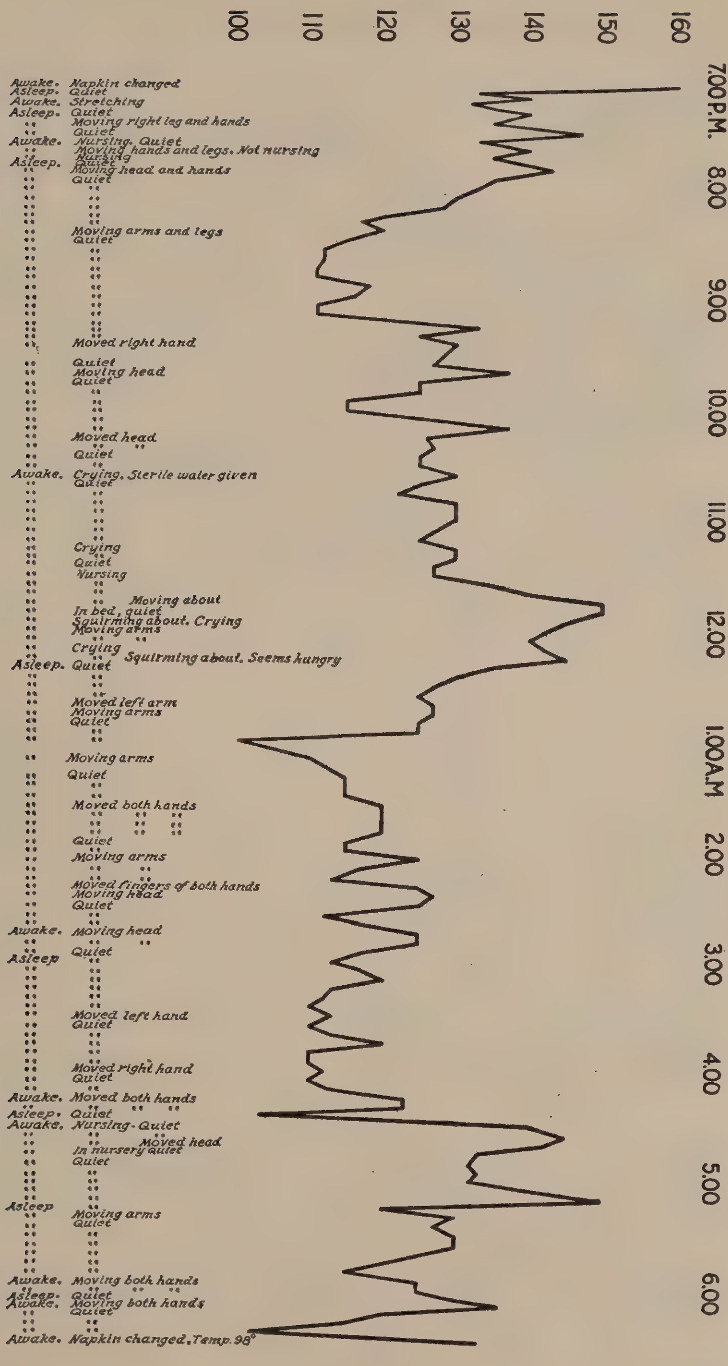

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FIG. 11. Pulse-rate curve for S——ns, July 1, 1911.
Age, 3 days; weight, 4.3 kilograms. See, also, fig. 12.

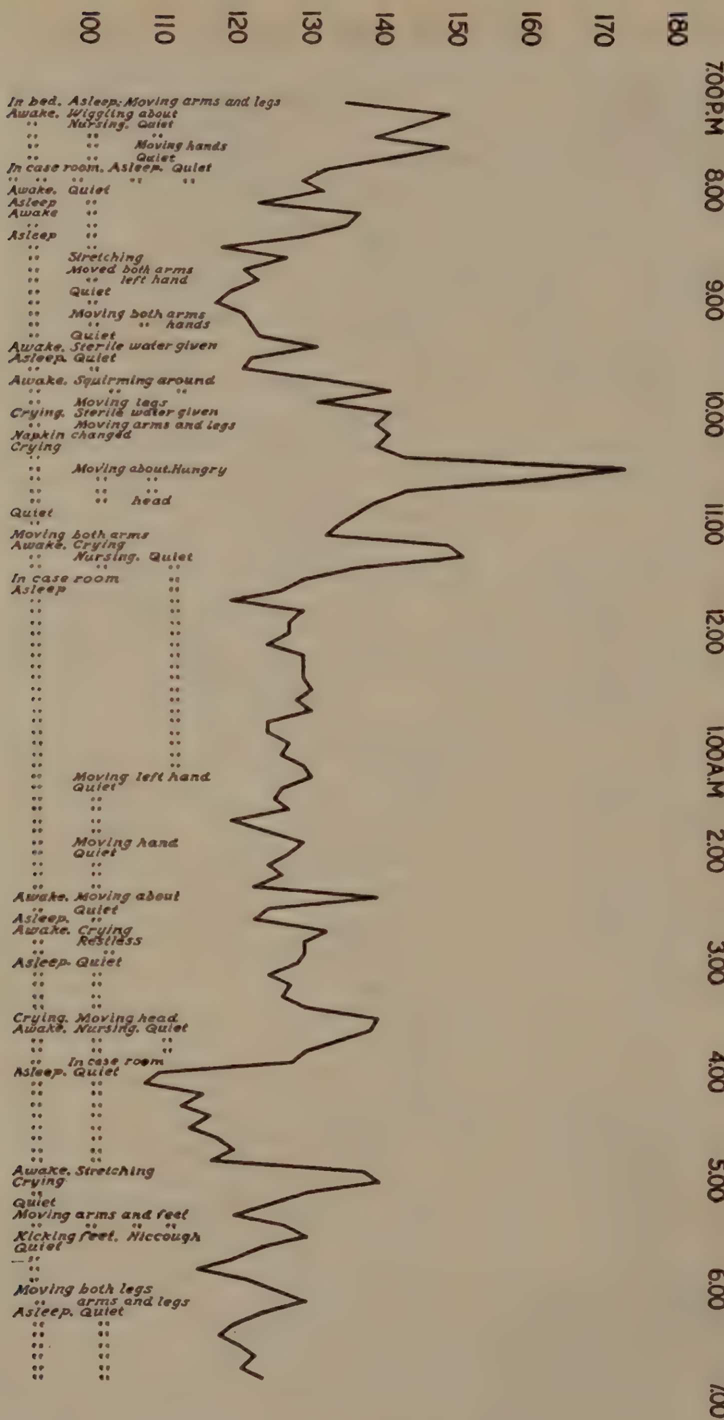

Fig. 12. Pulse-rate curve for S——ns, July 6, 1911. Age, 8 days; weight, 4.0 kilograms. See, also, fig. 11.

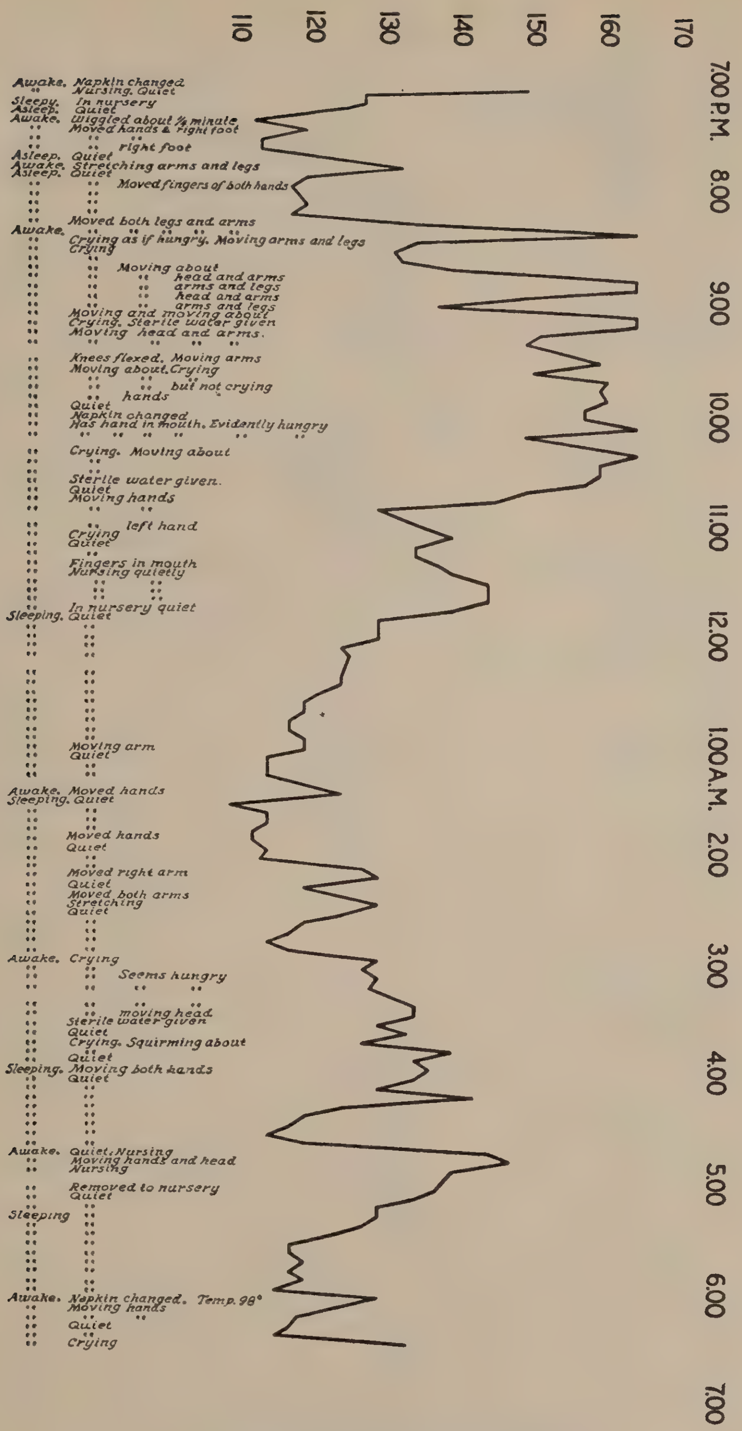

FIG. 13. Pulse-rate curve for Dow, July 1, 1911.
Age, 4 days; weight, 2.5 kilograms.

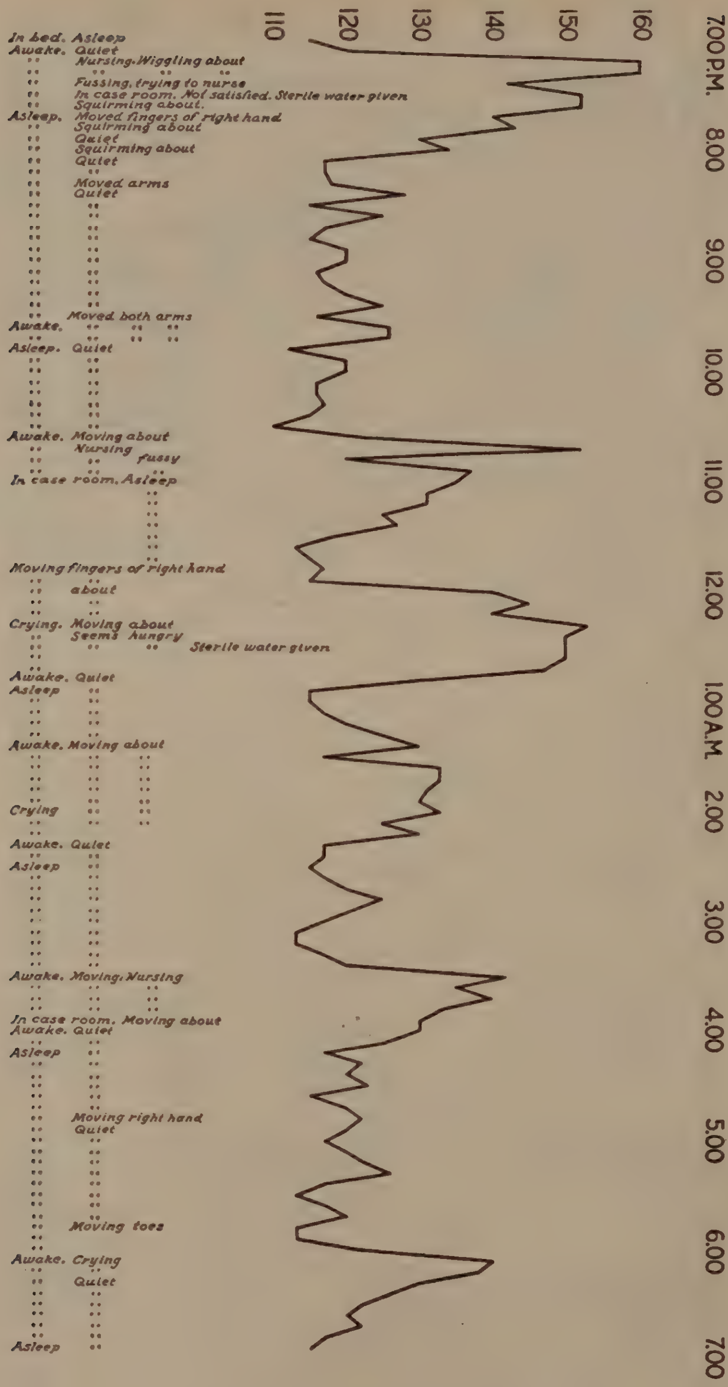

FIG. 14. Pulse-rate curve for Weldon, July 6, 1911.
Age, 8 days; weight, 3.0 kilograms.

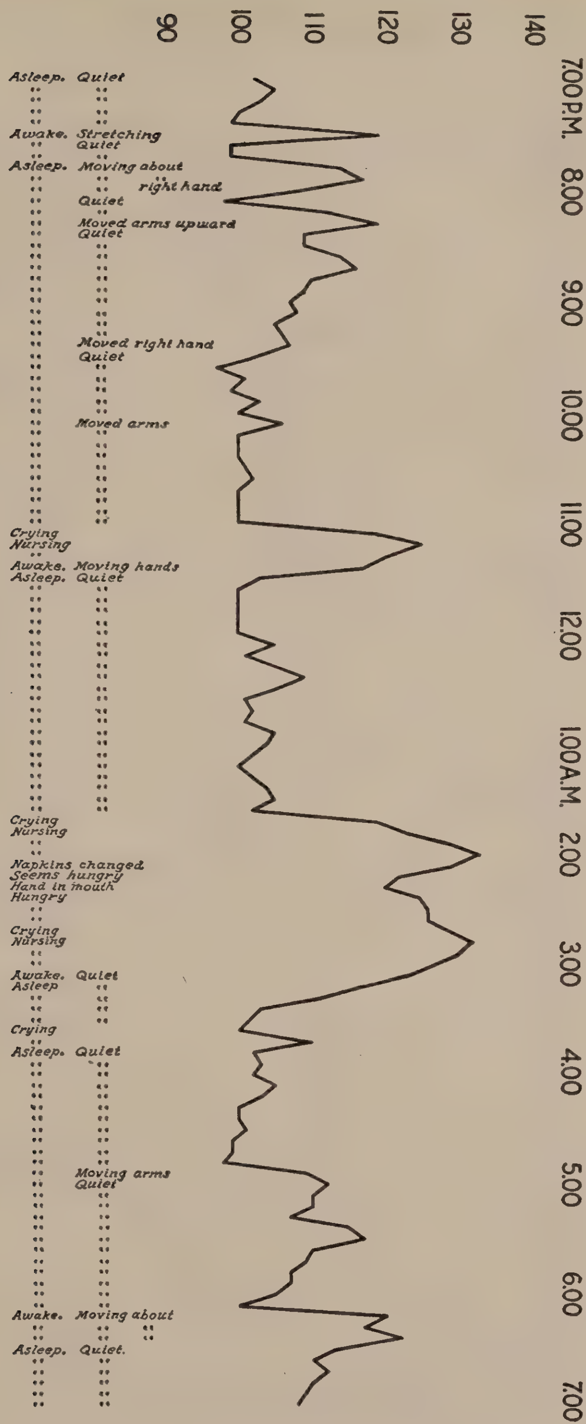

FIG. 15. Pulse-rate curve for Herbert W., July 13, 1911.
Age, 5 weeks; weight, 4.8 kilograms.

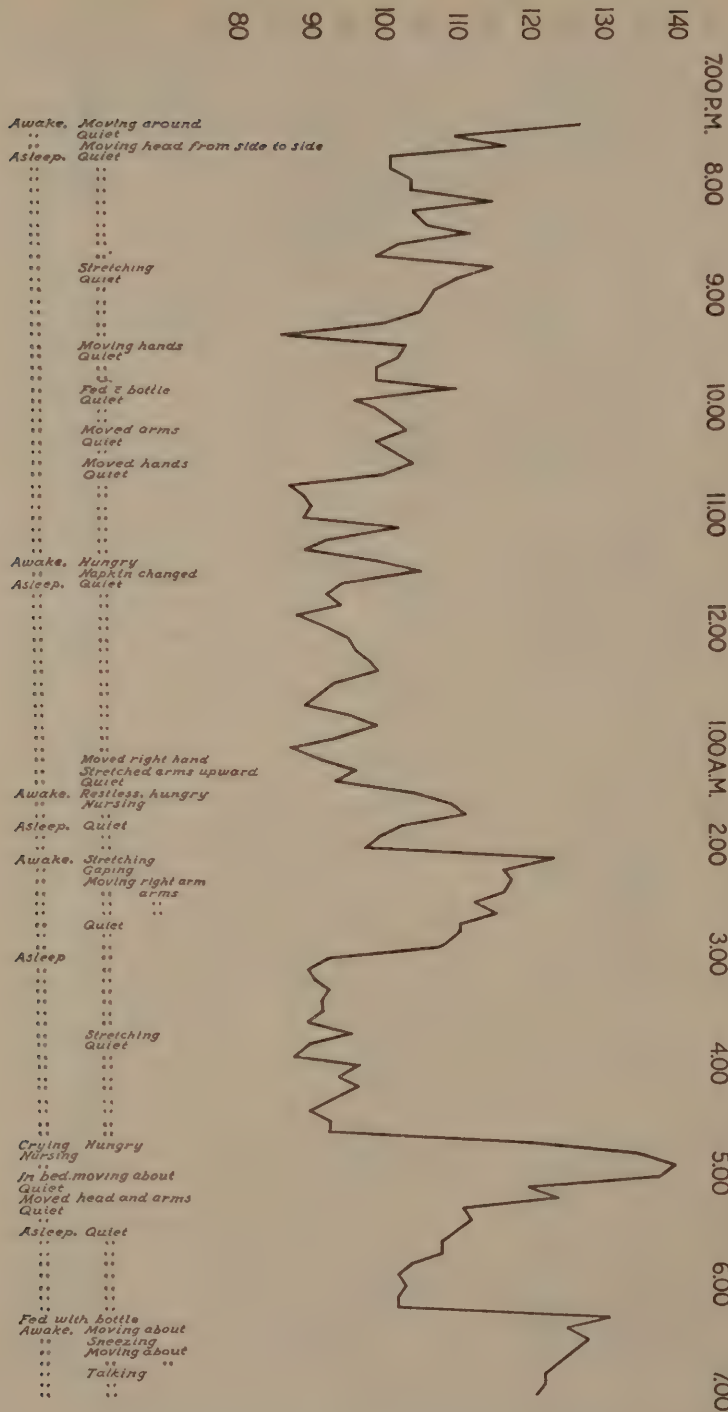

FIG. 16. Pulse-rate curve for Rita McL., July 14, 1911.
Age, 3 months; weight, 6.6 kilograms.

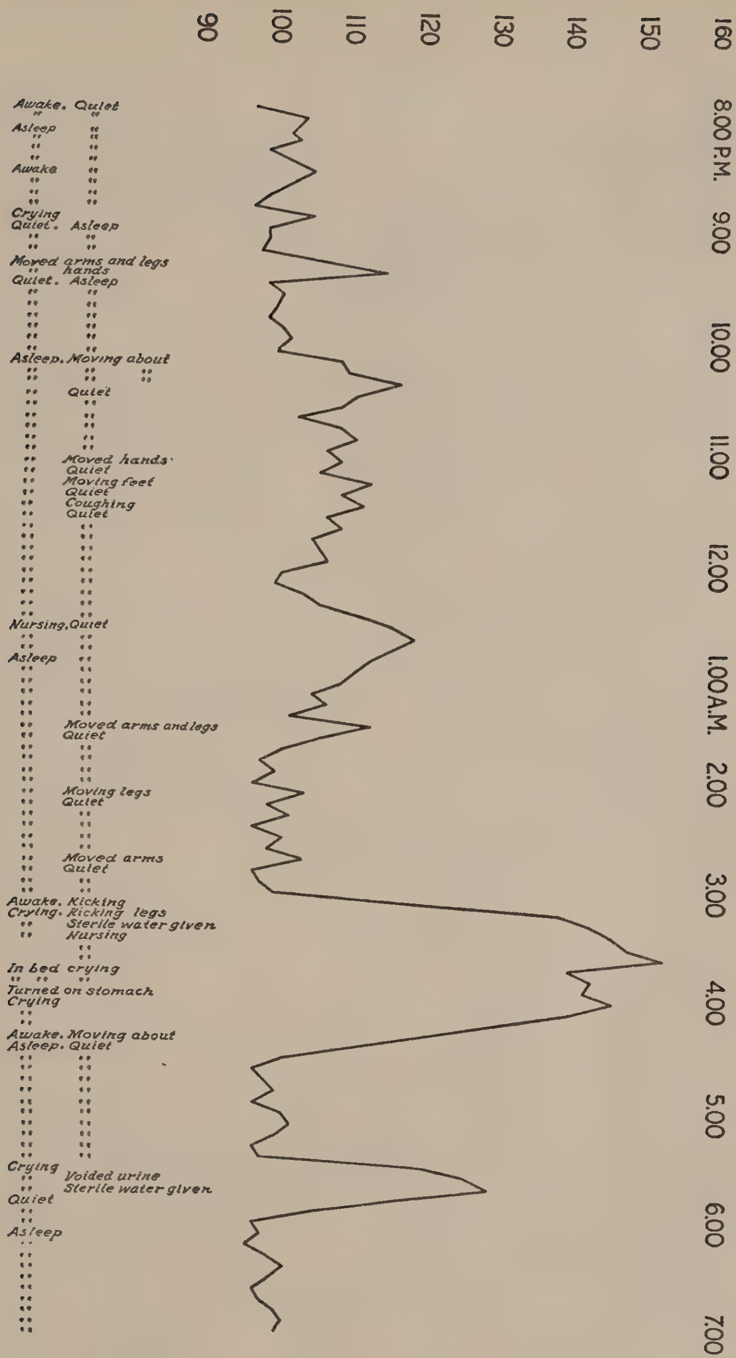

FIG. 17. Pulse-rate curve for Paul, July 12, 1911.
Age, 3 months; weight, 5.5 kilograms.

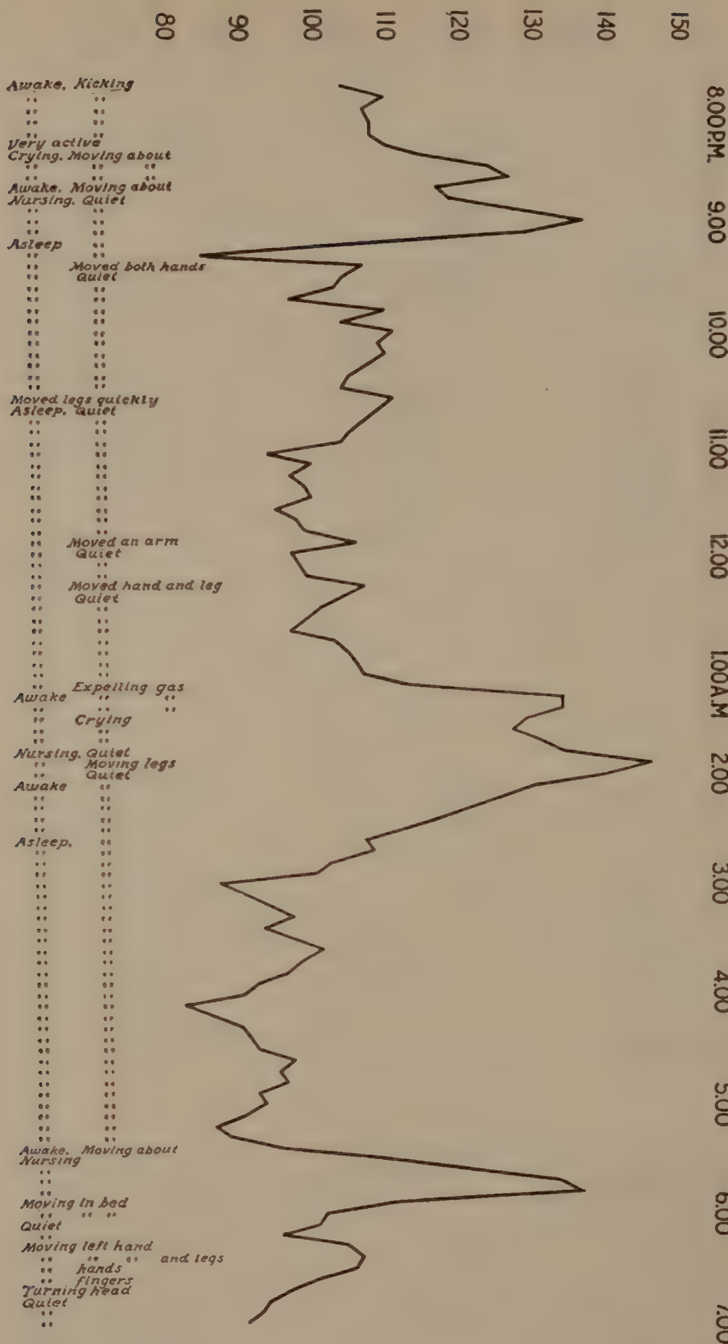

FIG. 18. Pulse-rate curve for Tremballe, July 12, 1911.
Age, 5 months; weight, 5.7 kilograms.

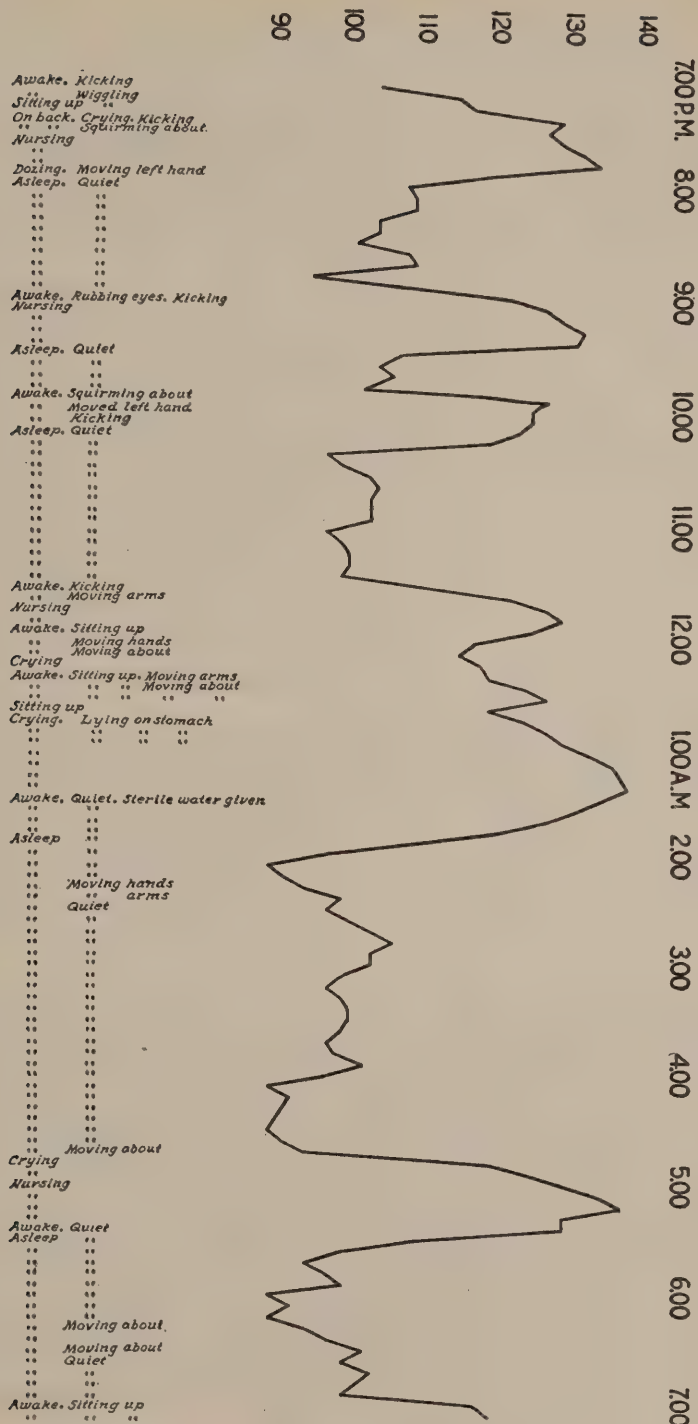

Fig. 19. Pulse-rate curve for Christine D., July 13, 1911.
Age, 7 months; weight, 7. 3 kilograms.

RECORDS OBTAINED DURING OBSERVATIONS WITH THE RESPIRATION APPARATUS.

The observations just discussed were only preliminary in character and were necessarily liable to more or less error. We have, however, a large number of pulse records which were subsequently made while the infant was under constant conditions in the respiration chamber. These records were likewise obtained by the use of the stethoscope according to the method previously described.[1]

It was frequently noted by the observer that the pulse-rate varied considerably during the minute of counting, particularly with very young infants. Thus, while the pulse-rate might be 20 beats in the first 10 seconds of the count, during the next 10 seconds it might fall to 18 beats, with similar variations throughout the whole minute. The pulse-rate was usually counted for one complete minute, but if the infant was crying it was counted for a half minute. At times when it was impossible to hear the pulse beat, the regular rhythm was counted by the observer and the count resumed by picking up the beats again when they became audible. Except during periods of crying, the pulse beats could be counted with a high degree of accuracy, but with the rapid pulse of severe crying slight errors unquestionably crept into the count. The arrhythmical pulse-rate of normal infants has recently been very extensively studied by Hecht.[2]

As already stated, we feel that the possibility for error in this method of taking the pulse records is too great and that some automatic form of recording the pulse-rate should be substituted. Every effort was made, however, to obtain pulse records as nearly exact as possible with this method, so that the pulse curves secured during the observations with the respiration chamber may very properly be carefully studied and relationships established with other records obtained at the same time.

RELATIONSHIP BETWEEN PULSE-RATE AND MUSCULAR ACTIVITY.

The simultaneous measurements of the pulse-rate by means of the stethoscope and of the muscular activity by the kymograph enable us to make sharp comparisons between these two factors. Such a comparison is made in figures 20 and 21, in which the kymograph curves obtained with two subjects are compared with the curves for the records of the pulse-rate during the same period of time.

The pulse and activity curves obtained for E. R. in the observation on April 12, 1913, are given in figure 20. The kymograph record shows that after a period of activity from $3^h\ 3^m$ p. m. to about $3^h\ 16^m$ p. m. there was a short period of comparative quiet, *i. e.*, from $3^h\ 16^m$ p. m.

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[1] See p. 61.

[2] Hecht, Der Mechanismus der Herzaktion im Kindesalter, seine Physiologie und Pathologie, Ergebnisse d. inn. Med. u. Kinderheilkunde, 1913, **11**, p. 324.

to $3^h\,36^m$ p. m., and that the last period from $5^h\,07^m$ p. m. to $5^h\,31^m$ p. m. was also sufficiently quiet to be characterized as activity II[1]. The remainder of the time the infant was quite active, so that experimental observations of the minimum metabolism were impossible. A close examination of the kymograph and pulse curves shows that there is a striking parallelism between them. Thus, from $3^h\,03^m$ p. m. to about $3^h\,16^m$ p. m., the infant was restless, with a high pulse-rate, while between $3^h\,16^m$ p. m. and $3^h\,36^m$ p. m., the activity was at a minimum

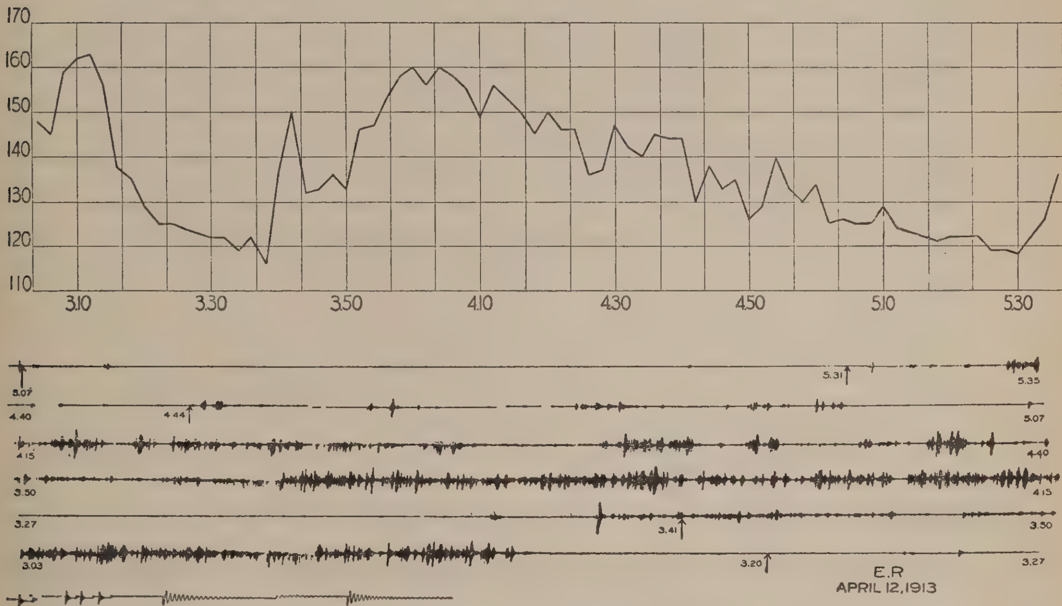

FIG. 20. Pulse-rate and kymograph curves for E. R., April 12, 1913.

and the pulse-rate was low. About $3^h\,39^m$ p. m. the pulse-rate again rose, the rise being accompanied by increased external activity. This reached a maximum about 4 o'clock and a period of decreasing activity followed until the infant became quiet at about $5^h\,7^m$ p. m. From that time until it waked up, just before the end of the observation, the infant was quiet with a minimum pulse-rate. Thus we see complete uniformity in both curves.

A second set of curves, which was obtained with E. N. on May 23, 1913, is given in figure 21. These curves also show a general parallelism between the activity and the pulse-rate, with an apparently anomalous condition between $4^h\,25^m$ p. m. and $4^h\,40^m$ p. m. At this time the pulse-rate was distinctly higher, while the kymograph record,

[1]For a discussion of the method adopted for designating the various degrees of muscular activity, see p. 130 and 136.

although not a perfectly smooth line, indicates no major movements. Another instance of fluctuating pulse-rate unaccompanied by changes in the kymograph record is seen in the period between 5^h 10^m p. m. and 5^h 30^m p. m. We thus have a general indication of uniformity between the pulse curve and the kymograph record, with a possibility of considerable fluctuation in the pulse-rate which is unaccompanied by external muscular activity. This feature will receive special consideration later.

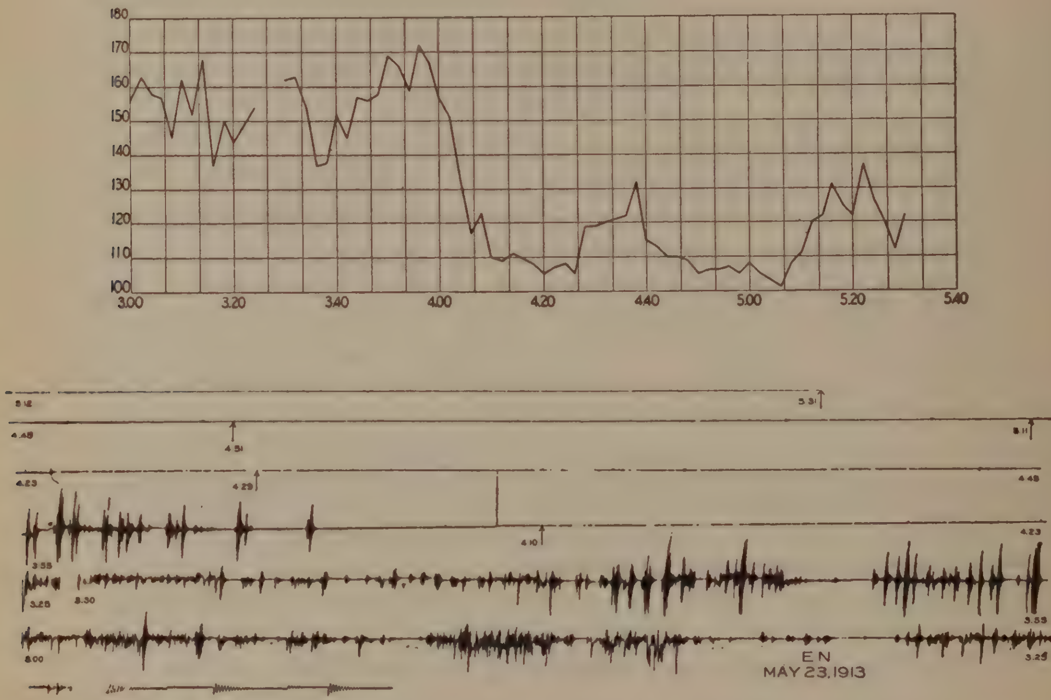

FIG. 21. Pulse-rate and kymograph curves for E. N., May 23, 1913.

An examination of the 193 kymograph records obtained in this series of experiments with infants shows the same general uniformity between the pulse-rate and the muscular activity as do the two specimen sets of observations given in figures 20 and 21. There are, however, a sufficient number of well-defined instances of alterations in the pulse-rate, unaccompanied by changes in muscular activity, to justify the assumption that an increase in pulse-rate is not necessarily a result of extraneous activity.

As further evidence of the uniformity between muscular activity and pulse-rate, particularly during periods of restlessness, we present in figures 22 to 37 comparisons of portions of kymograph and pulse-rate curves obtained with a number of subjects. This collection of kymo-

graph curves is also of particular interest, since they are selected, for the greater part, to show the change from activity to repose, or the reverse. The bracketed portions of the kymograph curves correspond to the pulse curves.

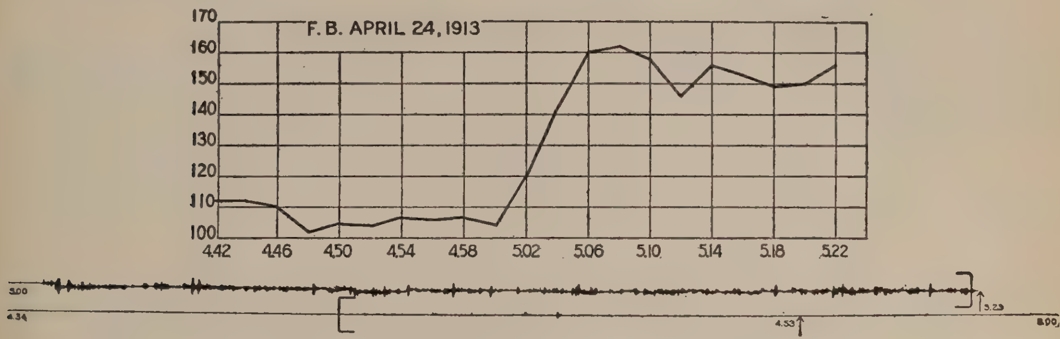

FIG. 22. Pulse-rate and kymograph curves for F. B., April 24, 1913.

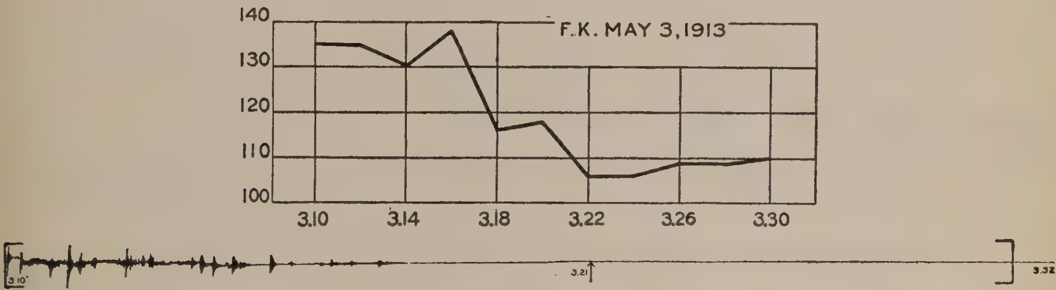

FIG. 23. Pulse-rate and kymograph curves for F. K., May 3, 1913. $3^h\ 10^m$ p. m. to $3^h\ 30^m$ p. m.

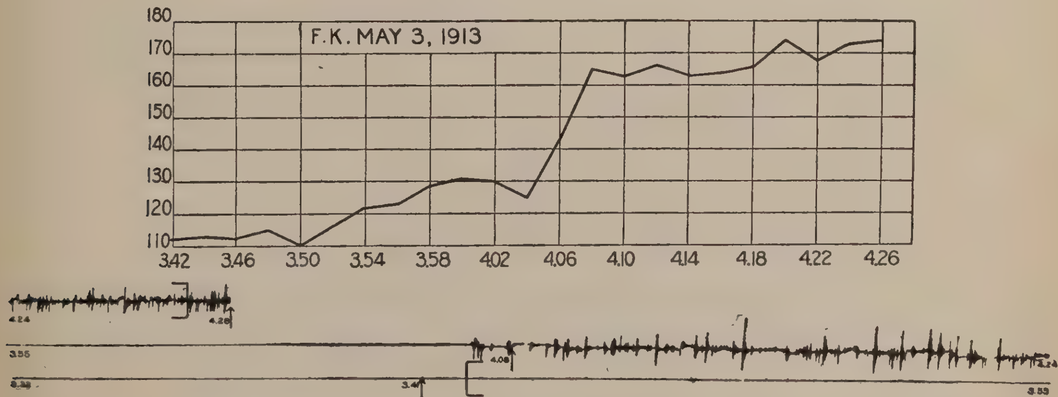

FIG. 24. Pulse-rate and kymograph curves for F. K., May 3, 1913. $3^h\ 42^m$ p. m. to $4^h\ 26^m$ p. m.

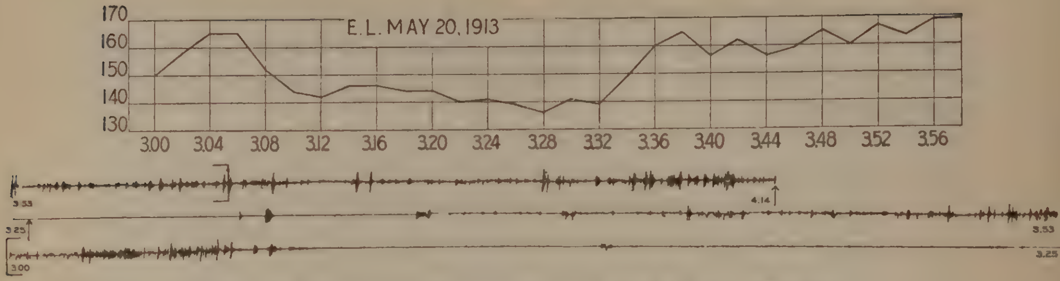

FIG. 25. Pulse-rate and kymograph curves for E. L., May 20, 1913.

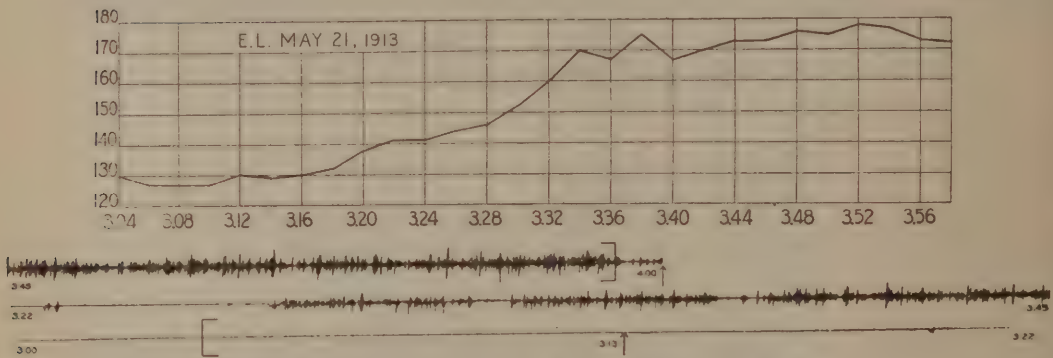

FIG. 26. Pulse-rate and kymograph curves for E. L., May 21, 1913.

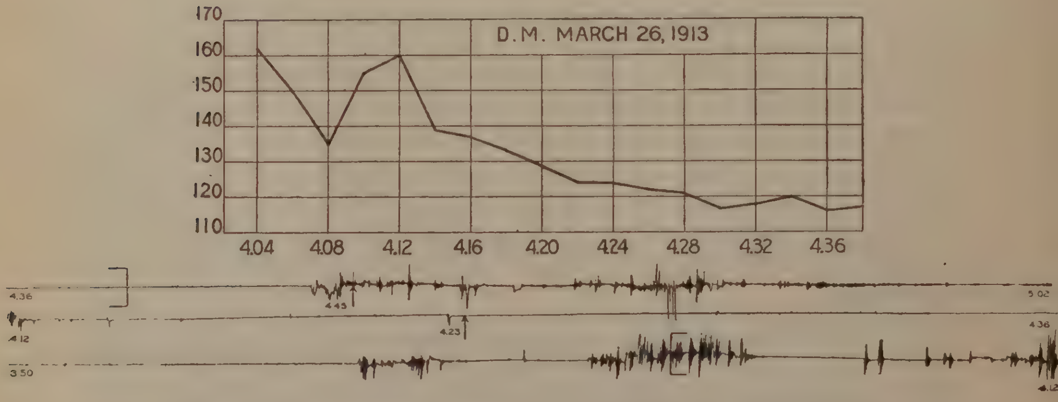

FIG. 27. Pulse-rate and kymograph curves for D. M., March 26, 1913.

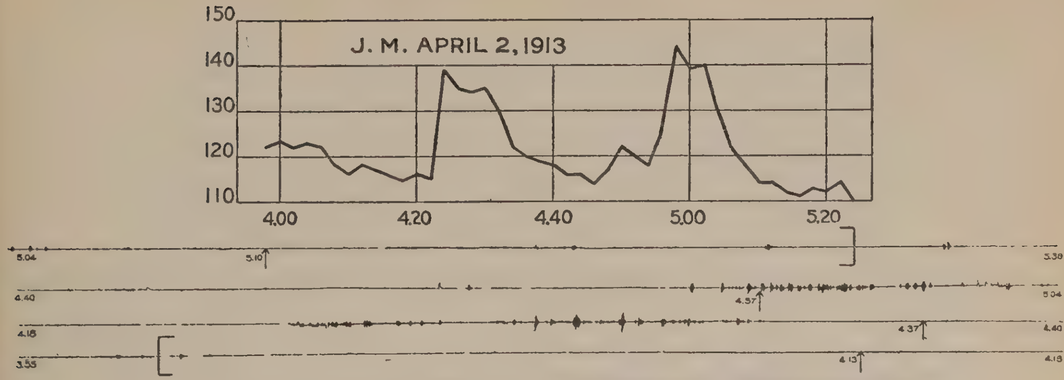

FIG. 28. Pulse-rate and kymograph curves for J. M., April 2, 1913.

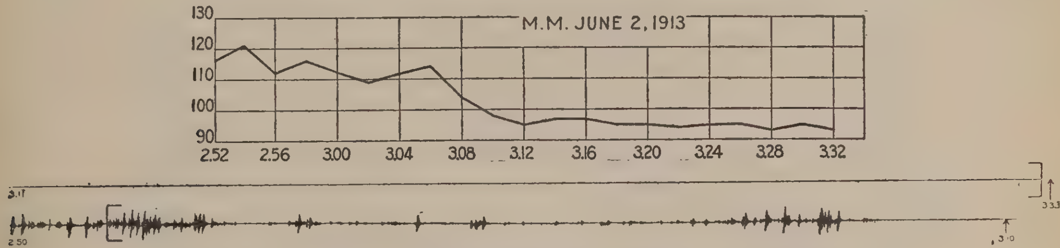

FIG. 29. Pulse-rate and kymograph curves for M. M., June 2, 1913.

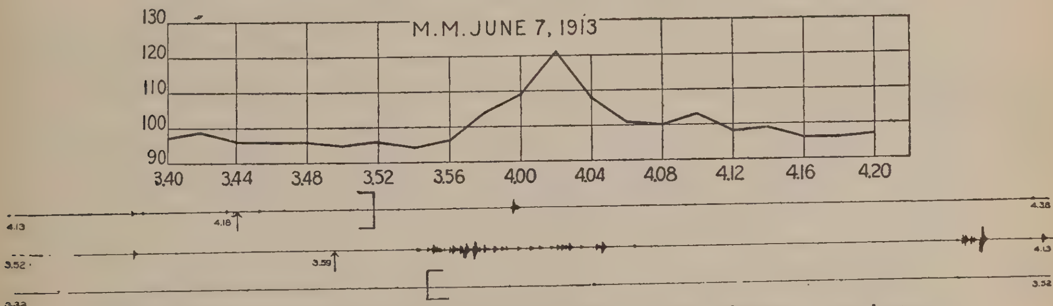

FIG. 30. Pulse-rate and kymograph curves for M. M., June 7, 1913. $3^h\ 40^m$ p. m. to $4^h\ 20^m$ p. m.

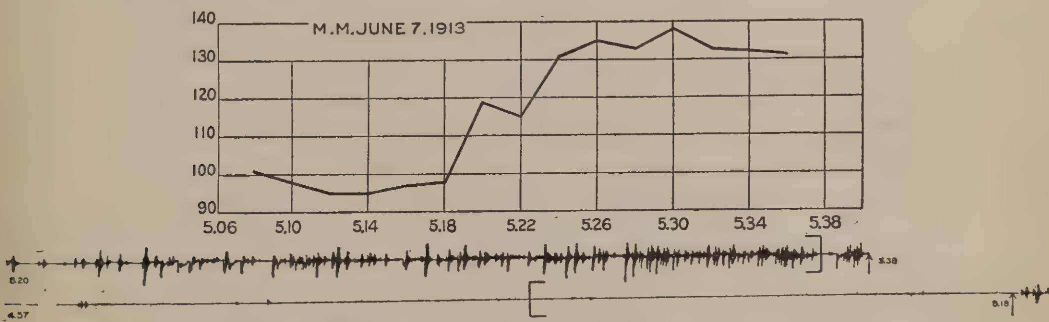

FIG. 31. Pulse-rate and kymograph curves for M. M., June 7, 1913. $5^h\ 8^m$ p. m. to $5^h\ 36^m$ p. m.

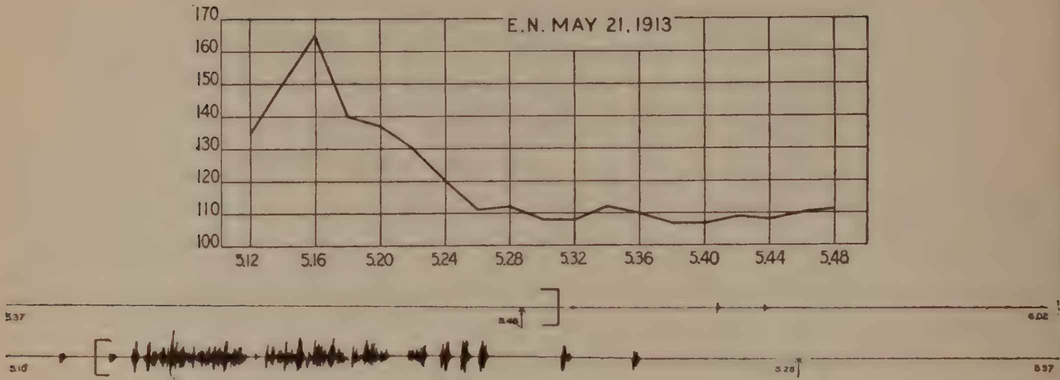

FIG. 32. Pulse-rate and kymograph curves for E. N., May 21, 1913.

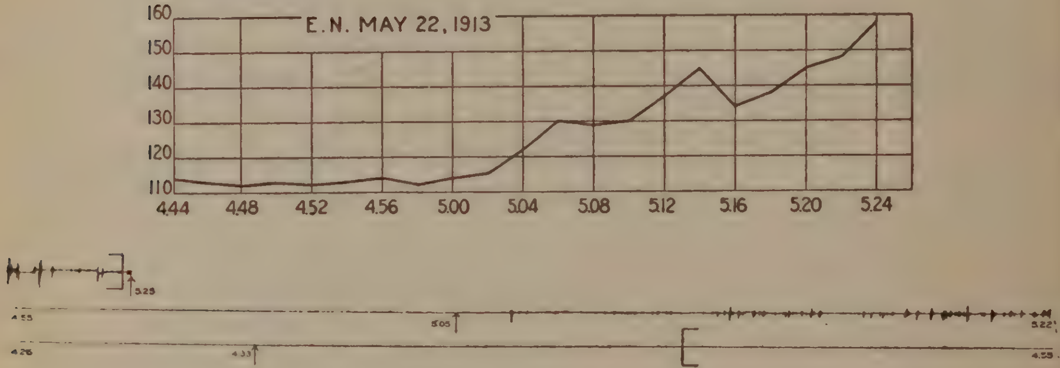

FIG. 33. Pulse-rate and kymograph curves for E. N., May 22, 1913.

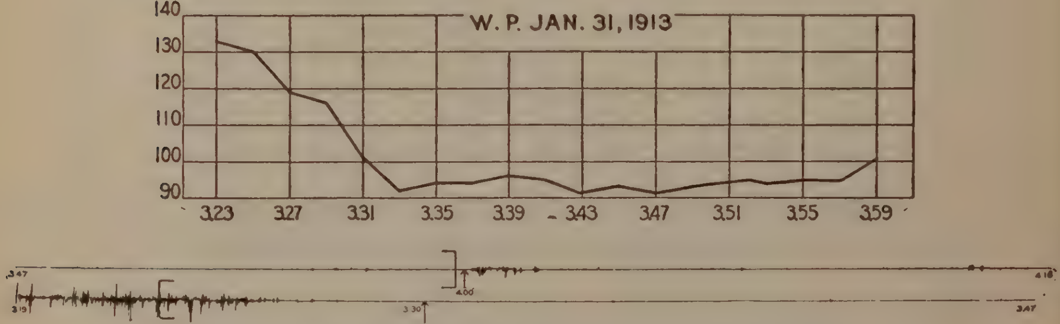

FIG. 34. Pulse-rate and kymograph curves for W. P., January 31, 1913.

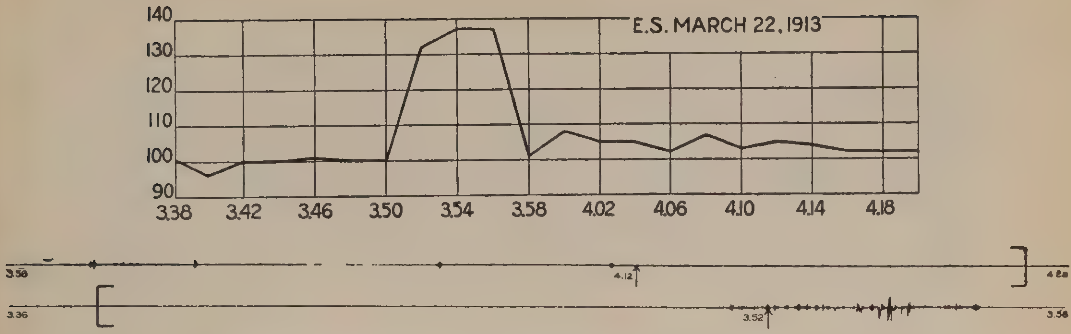

FIG. 35. Pulse-rate and kymograph curves for E. S., March 22, 1913.

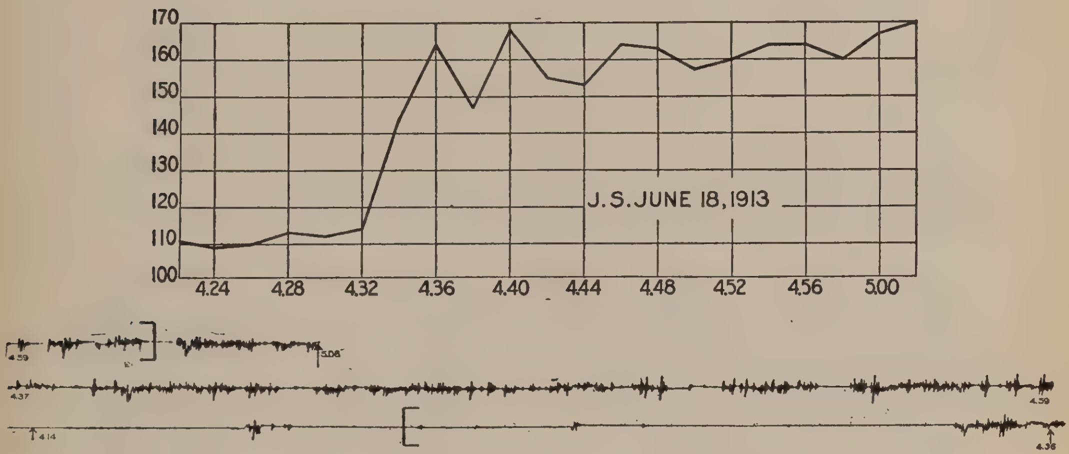

FIG. 36. Pulse-rate and kymograph curves for J. S., June 18, 1913.

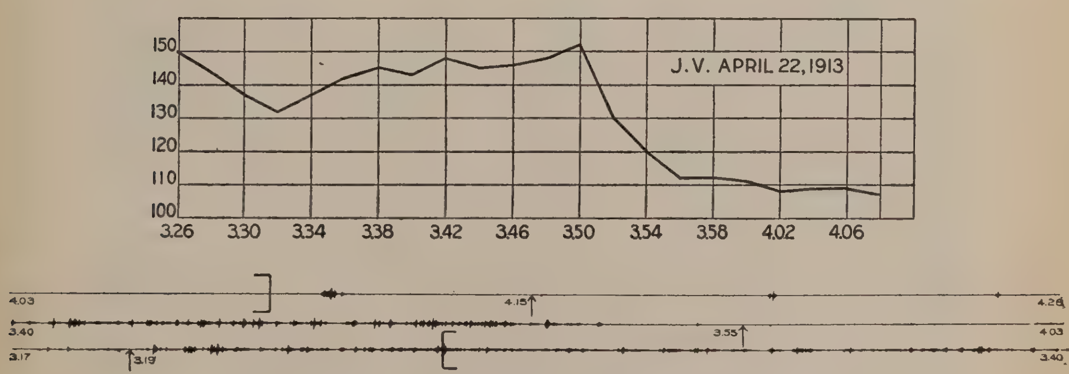

FIG. 37. Pulse-rate and kymograph curves for J. V., April 22, 1913.

EFFECT OF CHANGES IN ACTIVITY ON THE PULSE-RATE AT DIFFERENT AGES WITH THE SAME INFANT.

The extreme sensitivity of the pulse-rate to major changes in muscular activity has already been shown, but it is also important to note whether or not this sensitivity altered materially with increasing age. With one of the infants, J. V., we were able to make observations when she was 3½ months old, with a body-weight of 1.9 kilograms, and again when she was 7½ months old, with a body-weight of 3.3 kilograms. The curves obtained on January 25 and on May 27 are therefore compared in figure 38.

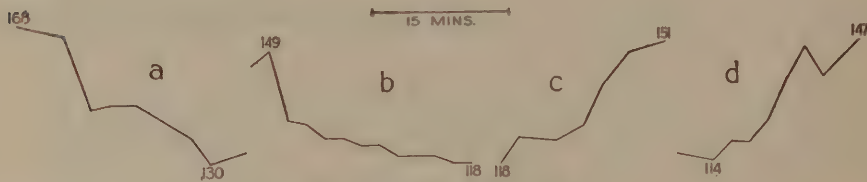

FIG. 38. Pulse-rate curves with J. V.

a. January 25, 1.9 kilograms, 3½ months, awake and crying vigorously, restless, quiet (asleep).
b. May 27, 3.3 kilograms, 7½ months, moving and grumbling, then quiet.
c. January 25, 1.9 kilograms, 3½ months, quiet (asleep), moved, cried, restless, cried.
d. May 27, 3.3 kilograms, 7½ months, quiet, moving, moving and grumbling.

In the period covered by the first curve (*a*) for January 25, *i. e.*, from 3^h 35^m p. m. to 4^h p. m., the infant was at first awake and restless, then quieted down until she fell asleep. The pulse-rate fell from 168 to 130 per minute during this period. The second curve for this day (*c*) shows a change in the pulse-rate from 118 at 4^h 18^m p. m., when the infant was quietly sleeping, to 151 at 4^h 36^m p. m., when she was awake, restless, and crying. In the first instance the fall in the pulse-rate of 38 beats required 25 minutes; in the second instance the rise in the pulse-rate of 33 beats took place in 18 minutes.

On May 27, the records (curve *b*) show that the pulse-rate fell from 149 at 3^h 14^m p. m., when the child was moving, to a minimum of 118 at 3^h 36^m p. m., when it was quiet, or 31 beats in 22 minutes. The second record for this day (curve *d*) shows a rise in the pulse-rate when the infant woke up and cried from 114 at 5^h 06^m p. m. to 147 at 5^h 22^m p. m., or an increase of 33 beats in 16 minutes.

Comparisons of this kind are always complicated by the possible variation in the intensity of the activity, although in the instances selected the external activity seemed to be essentially the same under the various conditions. There was no evidence of greater sensitiveness in the later observations, but there was a distinct tendency for the minimum pulse-rate at the age of 7½ months to be somewhat lower than at the age of 3½ months.

EFFECT OF CHANGES IN ACTIVITY ON THE PULSE-RATE WITH INFANTS OF THE SAME WEIGHT BUT DIFFERENT AGES.

In order to compare the effect of changes in activity on the pulse-rate of infants of the same weight but of different ages, a number of pulse curves are given in figures 39 and 40, these being grouped according to weight. These curves, like those previously shown, indicate the rapid reaction of the pulse-rate with the change in activity, the reac-

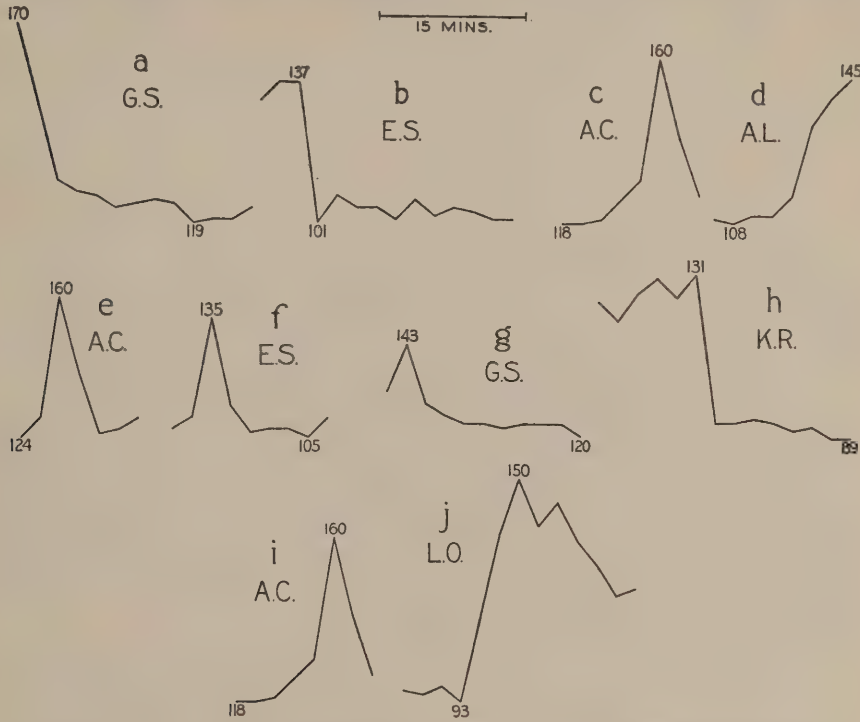

FIG. 39. Pulse-rate curves with infants of like weight but of different ages.

a and *b*. G. S., February 19, 3.3 kilograms, $2\frac{1}{2}$ months, crying and moving, then quiet; E. S., March 22, 3.0 kilograms, 5 months, moved and cried, moving, then quiet.
c and *d*. A. C., March 19, 3.0 kilograms, $1\frac{1}{2}$ months, quiet, moved, cried lustily, crying, quiet; A. L., June 16, 3.1 kilograms, $3\frac{1}{2}$ months, quiet, then moving and crying.
e and *f*. A. C., March 19, 3.0 kilograms, $1\frac{1}{2}$ months, moved, cried lustily, crying, then quiet; E. S., March 21, 3.0 kilograms, 5 months, quiet, moved, moving and crying, then quiet.
g and *h*. G. S., February 14, 3.2 kilograms, $2\frac{1}{2}$ months, moved and cried, restless, then quiet (asleep?); K.R., April 5, 3.1 kilograms, 4 months, moving and crying lustily, moving and crying, then quiet.
i and *j*. A. C., March 19, 3.0 kilograms, $1\frac{1}{2}$ months, quiet, moved, cried lustily, crying, quiet; L. O., February 28, 3.1 kilograms, 6 months, quiet, moved, moving and crying, moving a little.

tion being at times so rapid that we may reasonably question the accuracy of the record. The evidence given in these curves seems on the whole to indicate that the rapidity of the return to normal after crying and the increase when the infant waked up and cried are essentially the same with all of the infants, irrespective of age. This evidence does not agree with the results obtained in the earlier observations which were

made under less favorable circumstances. Obviously the curves given in figures 39 and 40 can not be directly compared with the long curves obtained in the hospital wards, since the former were secured under the absolutely uniform conditions obtaining in the respiration chamber and in relatively short experiments.

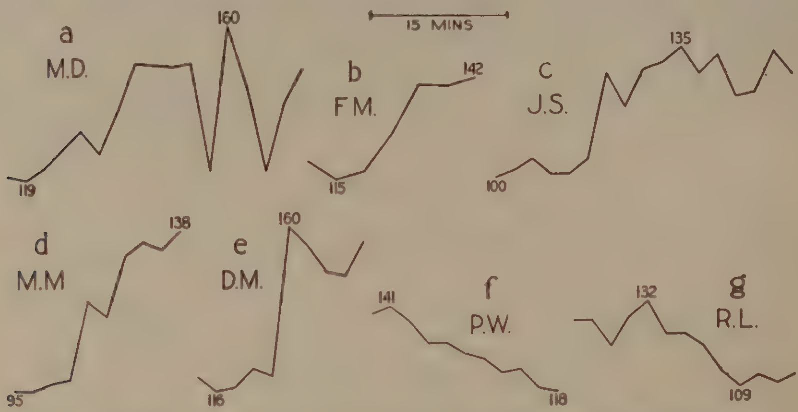

FIG. 40. Pulse-rate curves with infants of like weight, but of different ages.

a, *b*, and *c*. M. D., March 14, 4.0 kilograms, 3 weeks, quiet, then moved, crying and moving, quiet, moving, quiet, moving; F. M., January 22, 3.6 kilograms, 4 months, quiet, restless, restless and crying; J. S., June 11, 4.1 kilograms, 5½ months, moving slightly, fairly quiet then moved, moving and crying.

d and *e*. M. M., June 7, 5. 4 kilograms, 4½ months, quiet, moving, moving and grumbling, moving and crying; D. M., March 26, 5.2 kilograms, 11 months, quiet, moving and crying, moving, moving and crying.

f and *g*. P. W., April 1, 7.1 kilograms, 7 months, moving and grumbling, then quiet; R. L., May 16, 7.3 kilograms, 9 months, moving, then quiet.

EFFECT OF CHANGES IN ACTIVITY ON THE PULSE-RATE WITH INFANTS OF THE SAME AGE BUT WITH DIFFEERNT BODY-WEIGHTS.

Though the undeveloped, atrophic infants have a different reaction of the pulse-rate to variations in muscular activity from those found with normal infants, some of our data may still be used to throw light upon the question of the differences in the reaction with different body-weights. Curves have been plotted showing the changes in the pulse-rate accompanying changes in body-activity from quiet to crying, or the reverse, with a number of infants of the same age but with different body-weight; these are given in figures 41 and 42.

In only one of the comparisons is there a marked difference. The infants L. O. (curve *e*, figure 42) and J. S., (curve *f*, figure 42), with body-weights of 3.3 kilograms and 4.6 kilograms respectively, when compared with P. W. (curve *g*, figure 42) with a body-weight of 7.1 kilograms, show apparently a greater rapidity in the return to the normal than does the heavier infant. Little can be inferred from the other comparisons.

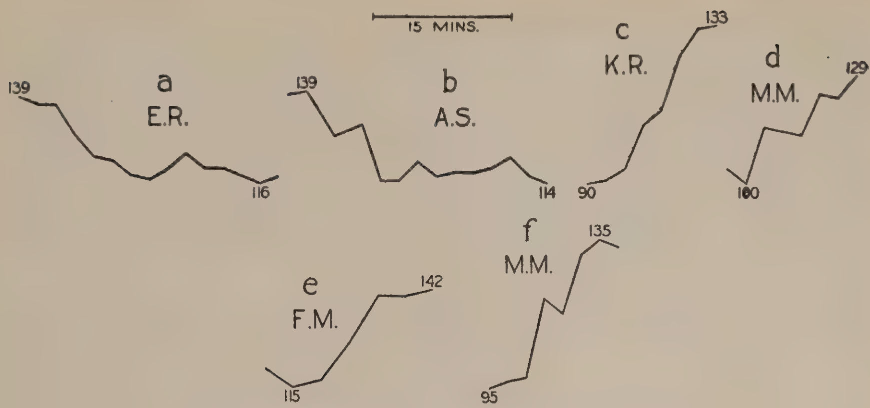

Fig. 41. Pulse-rate curves with infants of like age but of different weights.

a and *b*. E. R., April 14, 3 months, 4.5 kilograms, moving, then quiet, slight movements, quiet; A. S., April 1, 3 months, 6.0 kilograms, moving and grumbling, alternately quiet and moving, then quiet.
c and *d*. K. R., April 5, 4 months, 3.1 kilograms, quiet, moving and grumbling, moving and crying, moving and crying lustily; M. M., June 2, 4½ months, 5.4 kilograms, quiet, moving and crying, moving and grumbling, moving and crying.
e and *f*. F. M., January 22, 4 months, 3.6 kilograms, quiet, restless, restless and crying; M. M., June 7, 4½ months, 5.4 kilograms, quiet, moving, moving and grumbling.

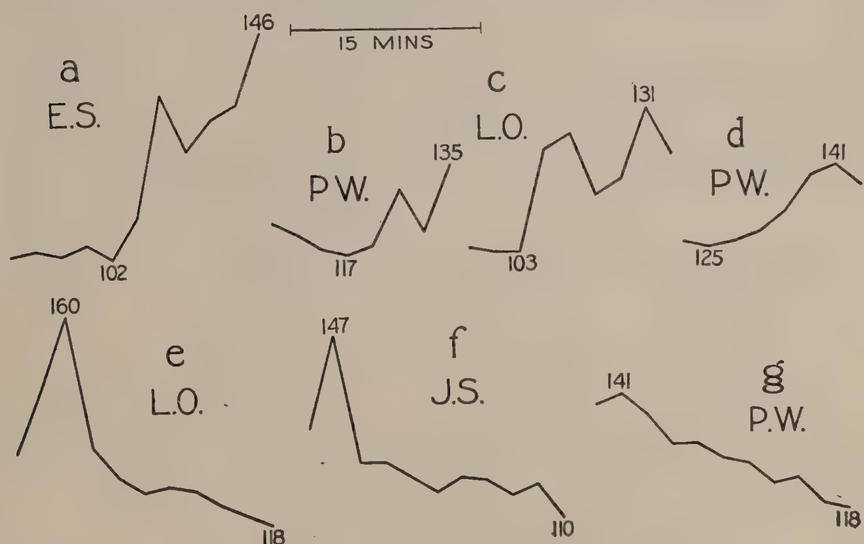

Fig. 42. Pulse-rate curves with infants of like age but of different weights.

a and *b*. E. S., March 21, 5 months, 3.0 kilograms, quiet, then crying and coughing, crying, moving, crying; P. W., April 3, 7 months, 7.1 kilograms, quiet, then moved, crying and moving, quiet, crying.
c and *d*. L. O., March 7, 6 months, 3.3 kilograms, quiet, then moved and turned over, moving: P. W., April 1, 7 months, 7.1 kilograms, quiet, moved, moving and grumbling.
e, *f*, and *g*. L. O., March 12, 6 months, 3.3 kilograms, moving and grumbling, coughed, then quiet; J. S., June 26, 6 months, 4.6 kilograms, moving and crying, then became quiet; P. W., April 1, 7 months, 7.1 kilograms, moving and grumbling, then quiet.

RELATIONSHIPS OF THE MUSCULAR ACTIVITY, PULSE-RATE, AND METABOLISM.

It has been a fundamental principle in all of our previous experimenting, with both adults and animals, that only periods of complete muscular repose should be used for comparison in studying the metabolism. The observations made with infants were also based upon this principle, the index used being the graphic records obtained with the mechanical registering device previously described. While for the major purposes of this publication, quiet periods were sought and the metabolism during periods of restlessness was only incidentally studied, we obviously unintentionally secured a large number of periods of more or less muscular activity. The relationships for the various muscular activities of the infant, the pulse-rate, and the total metabolism may therefore be readily discussed. To this end, a number of kymograph curves are reproduced in figures 43 to 48, showing the muscular activity of several infants.

From a consideration of the mechanical principles of the swinging crib, it can be seen that the heaviest and strongest infants would produce the greatest amplitude of vibration of the crib, this vibration being, in turn, transmitted through the writing point of the tambour to the kymograph. While it would be useless to compare the muscular activity of two infants by comparing the excursions of the writing point on the kymograph, nevertheless a general impression of the activity and strength of an infant considered as a living mass of tissue may be obtained by an inspection of these curves.

Accompanying the curves are tables giving the simultaneous records of the pulse-rate and the metabolism as computed on the basis of the total heat output per 24 hours. An estimate of the activity is also given in this table, using the basis of classification previously explained in table 23. For convenience in referring to these estimates, the key to the classification is given again here, being as follows:

I. Very quiet, probably asleep.
II. Slight movements, few in number.
III. Some activity, but generally quiet.
IV. Moderately active.
V. Distinctly active.
VI. Very active, most or all of the time.

A comparison of the curves with this estimated activity will serve to illustrate the method of estimation used in previous tables.

Observation with J. V., February 27, 1913.

The kymograph curve given in figure 43 was obtained with J. V. on February 27, 1913. This infant was very small and weak, weighing only 2.45 kilograms. She was restless throughout the observation and no period can be classified as activity I. As is usual with many of the observations, the preliminary period, which began at $3^h\ 6^m$ p. m., was characterized by considerable activity. At $3^h\ 34^m$ p. m. there was an ill-advised attempt to begin a new period, notwith-

standing the fact that considerable muscular activity immediately preceded the beginning of the period. Up to 4^h^ 12^m^ p. m., there was no approach to a condition of repose, but the period from 4^h^ 12^m^ p. m. to 4^h^ 42^m^ p. m. was the quietest period of the observation. The activity about 4^h^ 41^m^ p. m. was taken as indicating that the infant was waking up; as this would naturally be accompanied by considerable activity, a new period was begun. In the last period, that from 5^h^ 8^m^ p. m. to 5^h^ 38^m^ p. m., the curve is reasonably constant, the regularity of the line being broken by five or six movements. As a rule, perfectly smooth lines could rarely be obtained with this infant.

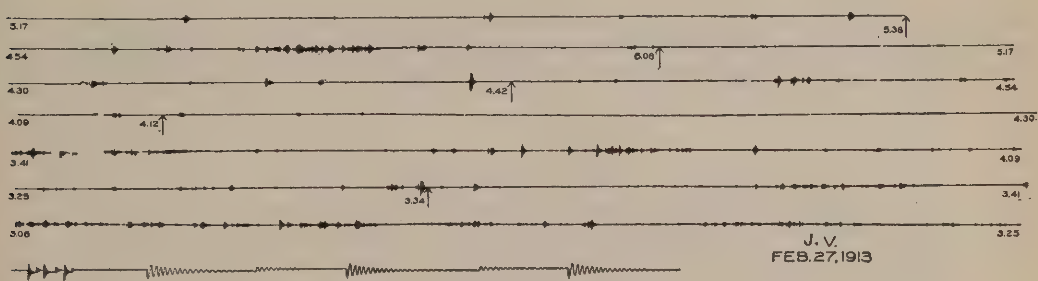

FIG. 43. Kymograph curve for J. V., February 27, 1913.

An examination of the estimated muscular activity given in table 24 shows that while it varied from III to VI, the estimates usually followed quite closely the total heat output. Thus, the two periods characterized as III represent 238 and 233 calories per 24 hours respectively, the two periods marked V correspond to 259 and 254 calories per 24 hours, and the preliminary period, which shows the most activity (VI), corresponds to 281 calories per 24 hours. The fluctuations in the pulse-rate are not very great in this particular observation, the minimum being 135 and the maximum 144; in general they follow the muscular activity and the total heat-production.

TABLE 24.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with J. V., February 27, 1913.*

Period.		Total heat-production per 24 hours.	Pulse-rate.	Activity.
		cals.		
3^h^ 06^m^ p.m. to	3^h^ 34^m^ p.m.*	281	143	VI
3 34	4 12	259	144	V
4 12	4 42	238	135	III
4 42	5 08	254	141	V
5 08	5 38	233	136	III

*Preliminary period,

A record of the sensitivity test is shown at the bottom of the kymograph curve, and the amplitude of the excursion and the regularity of the vibration vouch for the sensitiveness of the apparatus at that time.

Observation with J. V., April 22, 1913.

Inasmuch as the longest series of experiments with any infant was that made with J. V., and this infant was very small and weak, a second curve is shown, which was obtained on April 22, 1913 (see figure 44). The body-weight at this time was 2.93 kilograms. But one period can be characterized as activity II, *i. e.*, that between $3^h\ 55^m$ p. m. and $4^h\ 15^m$ p. m. The difficulties incidental

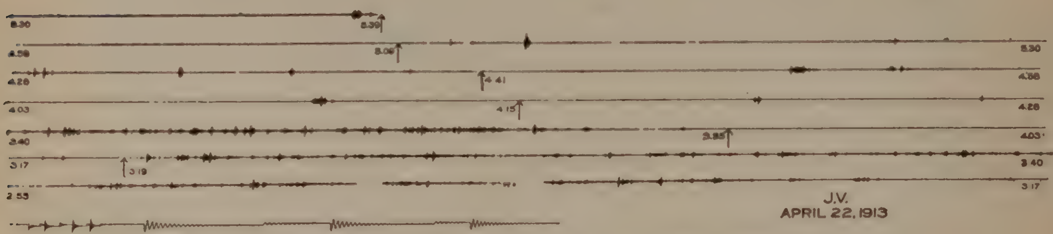

Fig. 44. Kymograph curve for J. V., April 22, 1913.

to differentiating sharply between the several classifications of activity may here be pointed out, in that during the period from $4^h\ 41^m$ p. m. to $5^h\ 9^m$ p. m., in which the activity is characterized as III, the heat-production was actually a little less than that in the period between $3^h\ 55^m$ p. m. and $4^h\ 15^m$ p. m., in which the activity was classified as II, while the pulse-rate was exactly the same (see table 25). On the other hand, in the preliminary and first periods, with the activity characterized as V and VI respectively, both the pulse-rate and the heat-production were considerably higher than in the other

Table 25.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with J. V., April 22, 1913.*

Period.		Total heat-production per 24 hours.	Pulse-rate.	Activity.
		cals.		
$2^h\ 55^m$ p.m. to	$3^h\ 19^m$ p.m.*	329	136	V
3 19	3 55	310	140	VI
3 55	4 15	233	110	II
4 15	4 41	247	115	III
4 41	5 09	218	110	III
5 09	5 39	235	114	III

*Preliminary period.

periods. Furthermore, in comparing these two periods with each other, we see that in the preliminary period when the activity was V and the pulse-rate 136, the heat-production was a little higher than that for the first experimental period, notwithstanding the fact that both the pulse-rate and the activity were higher in the latter period.

Throughout this whole monograph, it is important to note that the use of data obtained in the preliminary periods may lead to error, since the amount of carbon dioxide residual in the chamber may be somewhat less at the end of the period than at the start and the temperature conditions may not be ideal; hence the determinations as a whole may be less accurate than those of the subsequent periods. Nevertheless, it is interesting to note in this curve the occasional lack of agreement between the muscular activity record, the pulse-rate, and the total heat-production. As a possible explanation of this, we may

cite not only the opportunity for error in the determination of the gaseous exchange in a preliminary period, but the fact that the pulse-rates, particularly when the heart is beating rapidly, are difficult to count without photographic registration. Finally, there may always be a difference of opinion regarding the interpretation of the degree of activity shown by the curves. It is quite possible that the attempt to classify the activity under six heads is a refinement which the method will not warrant; unquestionably much less lack of agreement would be found if but four or even three classifications were used.

Observation with A. L., June 28, 1913.

The curve in figure 45 gives a record of the muscular activity during an observation made with A. L. This infant, who had at the time a body-weight of 3.15 kilograms, was evidently very active and much more vigorous than

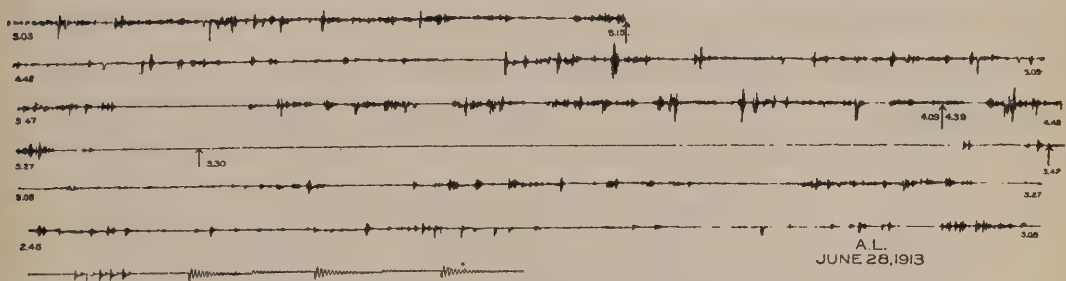

FIG. 45. Kymograph curve for A. L., June 28, 1913.

J. V., as may be seen by the frequency and the amplitude of the vibrations of the pointer on the kymograph. The activities ranged from II to VI, the quietest part of the curve being that between $3^h\ 30^m$ p. m. and $3^h\ 47^m$ p. m., only two small movements near the end breaking the continuity of the line

TABLE 26.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with A. L., June 28, 1913.*

Period.	Total heat-production per 24 hours.	Pulse-rate.	Activity.
	cals.		
$2^h\ 48^m$ p.m. to $3^h\ 30^m$ p.m.*	343	118	V
3 30 — 3 47	247	101	II
3 47 — 4 09	379	125	VI
4 39 — 5 15	374	137	VI

*Preliminary period.

which otherwise would have been characterized as I. Much greater variations in the pulse-rate are to be found with this infant than with J. V., the records ranging from 101 to 137 per minute (see table 26). The minimum pulse-rate was obtained in the period from $3^h\ 30^m$ p. m. to $3^h\ 47^m$ p. m., with an activity of II and a heat-production of 247 calories per 24 hours. In the preliminary period, when the activity was V, the pulse-rate was 118 and the heat-production 343 calories per 24 hours; the last two periods also show a high pulse-rate and heat-production, with an activity of VI. Here again there is general uniformity between activity, pulse-rate, and total heat-production. Although

the body-weight of A. L. was but little more than that of J. V., the kymograph curve for the former showed a distinctly greater amplitude and more frequency of movement and the metabolism was also greater. This demonstrates in an interesting manner the fact that A. L. was a more vigorous infant than J. V.

Observation with F. M., February 20, 1913.

Another infant, F. M., with a body-weight of 3.86 kilograms, showed unusually persistent activity throughout practically the whole of the observation on February 20, 1913 (see figure 46). The observation began at $3^h\ 18^m$

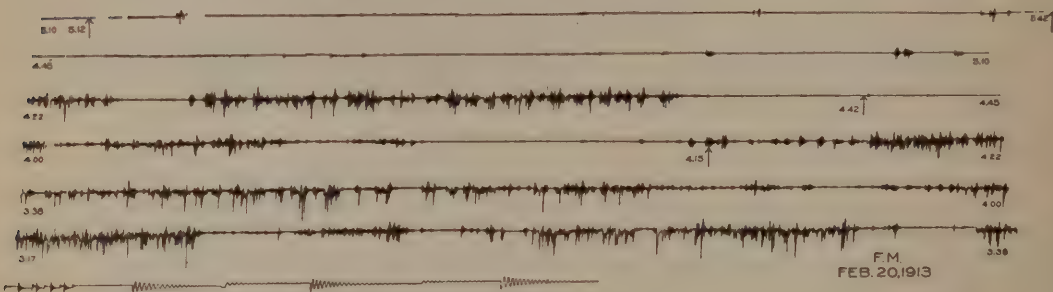

FIG. 46. Kymograph curve for F. M., February 20, 1913.

p. m., but the activity continued throughout two lengthy periods, *i. e.*, until $4^h\ 42^m$ p. m.; two reasonably quiet periods were subsequently obtained, with an activity of III and II respectively. As would be expected, the heat-production during the preliminary and first periods, when the activity was VI, was very large, being 535 calories per 24 hours in the preliminary period and 528 calories per 24 hours in the first experimental period (see table 27). In the period from $4^h\ 42^m$ p. m. to $5^h\ 12^m$ p. m., when the activity was III, the heat-production fell to 346 calories per 24 hours and the previous high pulse-rate of 141 and over dropped to 119. In the last period, that from

TABLE 27.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with F. M., February 20, 1913.*

Period.	Total heat-production per 24 hours.	Pulse-rate.	Activity.
	cals.		
$3^h\ 18^m$ p.m. to $4^h\ 15^m$ p.m.*	535	147	VI
4 15 to 4 42	528	141	VI
4 42 to 5 12	346	119	III
5 12 to 5 42	334	118	II

*Preliminary period.

$5^h\ 12^m$ p. m. to $5^h\ 42^m$ p. m., when the activity was slightly less and characterized as II, the pulse-rate fell but one point and the total heat-production was 334 calories per 24 hours. It will be seen that in this observation, also, the muscular activity, the pulse-rate, and the total katabolism follow almost parallel courses. Inasmuch as this infant was considerably heavier than either J. V. or A. L., the amplitude of the vibration of the pointer and the activity in general can not logically be used as indications of the body condition or strength of the infant except as showing that he should not in any sense be considered as weak.

Observation with M. M., June 5, 1913.

The kymograph curve for the infant M. M., obtained in the observation on June 5, 1913, has certain striking points, inasmuch as the minimum and maximum activity are very well shown (see figure 47). During the prelimi-

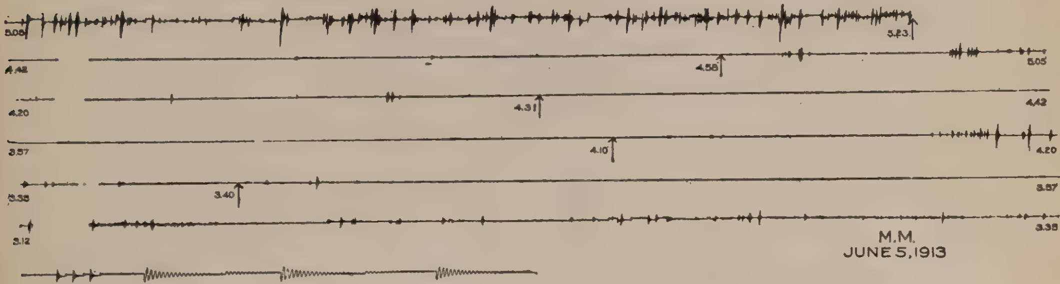

Fig. 47. Kymograph curve for M. M., June 5, 1913.

nary period from $3^h\ 12^m$ p. m. to $3^h\ 40^m$ p. m., the infant was somewhat restless, quieting down sufficiently about $3^h\ 35^m$ p. m. to justify the beginning of a new period at $3^h\ 40^m$ p. m. As a matter of fact, the infant was so quiet in the next period that the activity can be characterized as I (see table 28).

Table 28.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with M. M., June 5, 1913.*

Period.	Total heat-production per 24 hours.	Pulse-rate.	Activity.
	cals.		
$3^h\ 12^m$ p.m. to $3^h\ 40^m$ p.m.*	365	107	V
3 40 to 4 10	276	93	I
4 10 to 4 31	307	96	III
4 31 to 4 58	288	90	II
4 58 to 5 23	367	113	VI

*Preliminary period.

The activity in the last period, *i. e.*, that from $4^h\ 58^m$ p. m. to $5^h\ 23^m$ p. m., was sufficiently great to be classified as VI. This curve shows clearly the futility of attempting to graduate by kymograph records the exact degree of the activity and the heat-production, for although the curve appears to indicate that the activity in the last period (from $4^h\ 58^m$ p. m. to $5^h\ 23^m$ p. m.) was much greater than that in the preliminary period from $3^h\ 12^m$ p. m. to $3^h\ 40^m$ p. m., the metabolism is very nearly the same and the pulse-rate is only 6 beats higher in the last period. This also justifies the statement previously made that the measurements obtained in preliminary periods are not sufficiently reliable to admit of extended discussion. The fact that no greater metabolism is shown in the last period than in the preliminary period, although the activity appears to be greater, should therefore be considered as a deduction based upon single measurements in two individual periods, either of which may be liable to error. Furthermore, when comparing the pulse-rates it should be stated that although the average pulse-rate in the preliminary period was 107, the individual counts ranged from 95 to 120, while the pulse-rates in the last period, although the average was 113, actually varied from 93 to 124. Discrepancies such as these serve again to emphasize

the fact that only periods of complete muscular repose can logically be used in discussing infant metabolism.

In connection with the classification of the activity in the several periods, it is of interest to compare estimates made independently by two persons several weeks after the first estimate was made. This is done in table 29. The

TABLE 29.—*Comparison of original estimates of activity with later estimates made independently by two individuals.*

(Observation with M. M., June 5, 1913.)

Period.	Pulse-rate.	Estimates of activity.		
		Original.	Later.	
			Reader A.	Reader B.
3^h 12^m p.m. to 3^h 40^m p.m.*	107	V	V	V
3 40 — 4 10	93	I	I	II
4 10 — 4 31	96	III	III	III
4 31 — 4 58	90	I	I	II
4 58 — 5 23	113	VI	VI	VI

*Preliminary period.

only disagreements after several weeks, during which time several hundred records had been examined, are found in the estimates for the second and fourth periods in distinguishing between classifications I and II. No attempt was made to classify the activities beyond V, any degree of activity beyond this being classed as VI. While one might say that the activity in the last period was two or three times that of the first period, since it is classified as VI, this conclusion is not justifiable, as is shown by the records of the pulse-rate and the metabolism in these two periods.

Observation with F. K., May 2, 1913.

Another infant, F. K., with a body-weight of 5.68 kilograms, showed activities ranging from I to VI in the kymograph curve for May 2, 1913 (see figure 48). No curve previously given has shown a perfectly smooth line for an

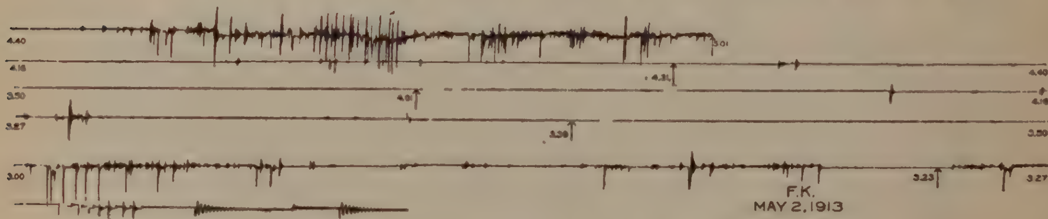

FIG. 48. Kymograph curve for F. K., May 2, 1913.

entire period, but such a line was obtained in the second experimental period of this observation, *i. e.*, that from 3^h 39^m p. m. to 4^h 1^m p. m. Incidentally this indicates how large an amount of experimental work must be done in order to secure a sufficient number of periods with minimum activity for comparison. Indeed, for the fundamental discussion of the comparative metabolism of infants, hardly one-third of our entire series of observations could be utilized.

An interesting comparison of the total metabolism, the pulse-rate, and the records of the activity for this observation is given in table 30. A general uniformity is observed, although the preliminary period (from 3^h 1^m p. m. to

$3^h\ 23^m$ p. m.) with an activity of VI has a heat-production and pulse-rate slightly less than the last period (that from $4^h\ 31^m$ p. m. to $5^h\ 1^m$ p. m.) with an activity of V. This again illustrates the anomalies observed in comparisons with the results obtained in the preliminary period.

TABLE 30.—*Comparison of the pulse-rate, metabolism, and muscular activity in observation with F. K., May 2, 1913.*

Period.		Total heat-production per 24 hours.	Pulse-rate.	Activity.
		cals.		
$3^h\ 01^m$ p.m. to	$3^h\ 23^m$ p.m.*	526	138	VI
3 23	3 39	446	121	IV
3 39	4 01	382	109	I
4 01	4 31	420	116	III
4 31	5 01	535	141	V

*Preliminary period.

Additional comparisons of the muscular activity, the pulse-rate, and the metabolism may be made by reference to the kymograph curves given with the discussion of the relationship between the muscular activity and the pulse-rate.[1] The data regarding the pulse-rates and the metabolism will be found in table 23,[2] which gives the statistics for all of the observations.

SIGNIFICANCE OF THE RELATIONSHIPS.

From the preceding discussion the conclusion may be drawn that only periods of complete muscular repose may be used in comparing the results obtained with different individuals and with the same individuals on different days. The total katabolism of the infant is the resultant of two factors: First, the metabolism due to the internal activity incidental to circulation and respiration and the general muscle tonus of the body, *i. e.*, maintenance metabolism; second, the metabolism due to the external muscular activity, which may vary from slight movements of the hand or fingers to violent movements incidental to severe crying.

The internal muscular activity of the infant may also be affected by the ingestion of food and, as with adults, it may be affected by the general condition of the body, such as in disease or immediately following severe illness. For a short time after feeding, provided essentially the same kind and amount of food is given, it may be assumed that the metabolism due to internal muscular activity is fairly constant[3] with an infant. The effect of the ingestion of food upon the internal muscular activity of the infant is discussed elsewhere in this report,[4] but here we compare primarily the metabolism during complete muscular repose and during various degrees of muscular activity.

The external muscular movements are recorded with considerable fidelity upon the kymograph drum by means of the registering appa-

[1]See p. 118. [2]See p. 84. [3]Schlossmann, Deutsche med. Wochenschr. 1911, **37**, p. 1635.
[4]See p. 145.

ratus described, but we have seen that this record does not give a comparative picture of the degree of activity of different infants. Consequently, for comparing the maintenance metabolism only periods in which the external muscular activity is eliminated should be used, since in the last analysis knowledge with regard to internal muscular activity is desired, uncomplicated by the increased metabolism due to external muscular activity. We believe that our evidence justifies us in asserting that we have two admirable indices for securing these ideal conditions of muscular repose for comparison, first, the graphic records obtained with the kymograph, and second, the pulse-rate. For comparing the metabolism of different infants, therefore, only those periods with records of complete muscular repose and with minimum pulse-rate can legitimately be employed.

RELATIONSHIP BETWEEN PULSE-RATE AND METABOLISM.

From the general pictures of the kymograph curves and the pulse curves, one may infer that the pulse-rate follows closely the muscular activity. Furthermore, since it has been shown that the relationship between the metabolism and the kymograph curves is comparatively constant, it is reasonable to expect that the pulse-rate will follow the metabolism. That this latter relationship is usually more nearly constant than the relationship between the metabolism and the record of the muscular activity is clearly indicated in a number of observations in which the kymograph record showed a complete absence of extraneous muscular activity, while the pulse records showed fluctuations.

An excellent illustration of this may be seen in the pulse and kymograph curves which were obtained in the observation of February 1, 1913, with the infant L. B. (see figure 49). Thus between 4 p. m. and

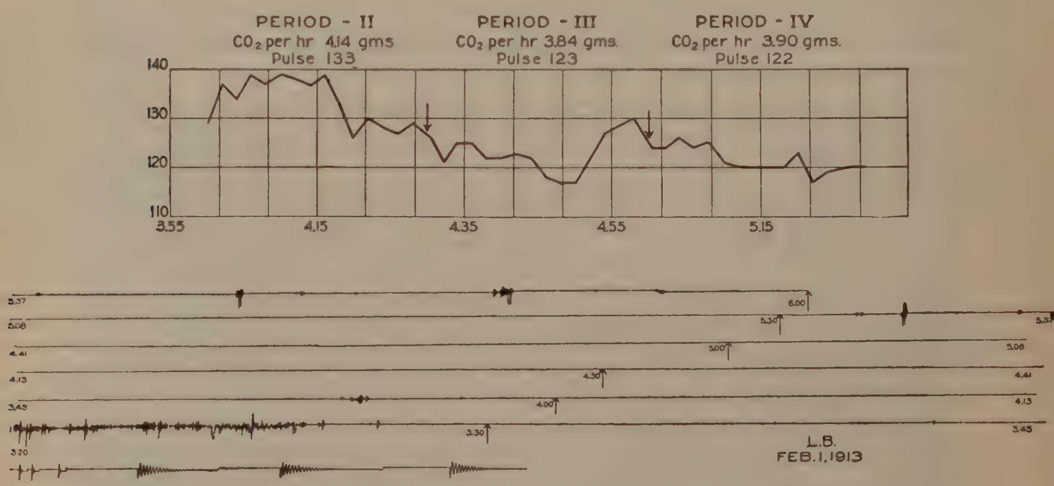

FIG. 49. Pulse-rate and kymograph curves for L. B., February 1, 1913.

$5^h\ 30^m$ p. m., one may assume that the activity was essentially of the grade I, *i. e.*, minimum. Nevertheless the pulse-rate is considerably higher in the period between 4 p. m. and $4^h\ 30^m$ p. m. than in the two following periods, as is shown by the pulse curve and the figures for the pulse-rate per minute. As a matter of fact, the total metabolism is likewise higher in the first period as is evidenced by the carbon-dioxide output per hour which is given on the pulse curve. In this curve, therefore, which excludes the extraneous activity, we find the pulse-rate following very closely the total metabolism. While the kymograph curve did not indicate muscular activity, nevertheless the pulse-rate gave evidence of an increased internal activity.

A comparison of the records obtained for the muscular activity, the pulse-rate, and the metabolism in the observation with A. D. on May 19, 1913, gives further evidence on this important point (see figure 50). In the two periods from $3^h\ 35^m$ p. m. to 4 p. m. and from $4^h\ 31^m$ p. m. to $4^h\ 54^m$ p. m., the muscular activity shown by the kymograph records would be classified as I. The pulse-rate in the first of these periods (period II) was 113 and in the second (period IV) 104. This variation in the pulse-rate is accompanied by a like variation in the carbon-dioxide production, which was 3.02 grams per hour in period II, and 2.66 grams per hour in period IV. Here again the pulse-rate is seen to be a closer index of the total katabolism than is the kymograph record.

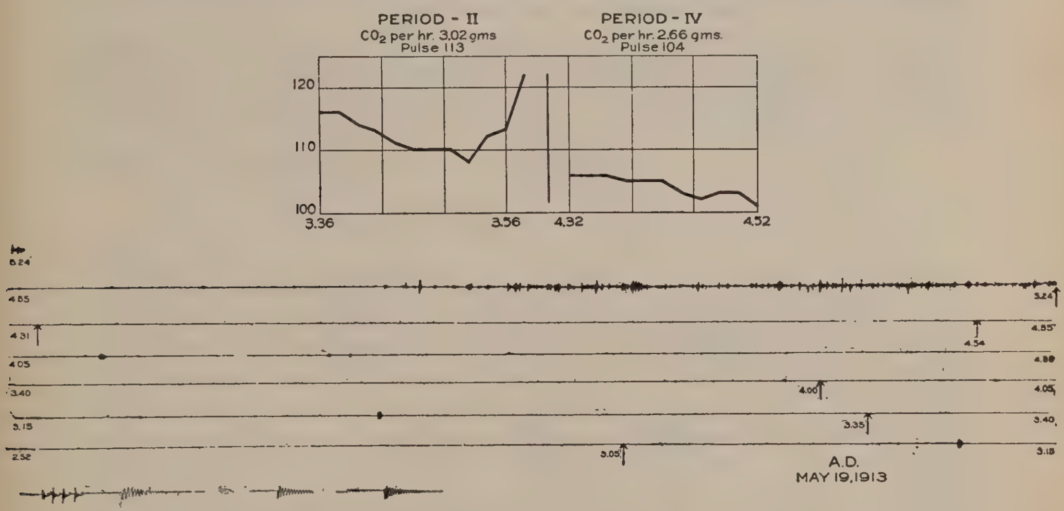

FIG. 50. Pulse-rate and kymograph curves for A. D., May 19, 1913.

Two selected periods which were obtained with the infant J. M. in the observation of April 4, 1913, are compared in figure 51. These periods, both of which had an activity of I, also show the pulse-rate and the carbon dioxide output in harmony, the pulse-rate in period I being 112 as compared with 97 in period VI, with a carbon-dioxide production of 7.08 grams per hour and 6.41 grams per hour respectively.

In this instance the kymograph record indicates a slightly greater activity in period I (from 3h 4m p. m. to 3h 29m p. m.) than in period VI (from 5h 10m p. m. to 5h 26m p. m.), which may account for at least a part of the increase in the metabolism.

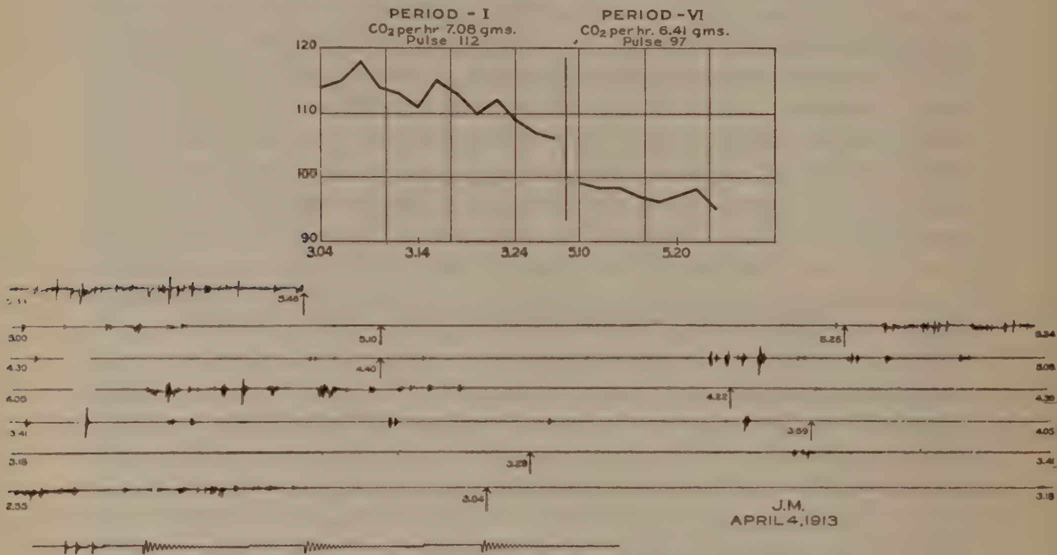

FIG. 51. Pulse-rate and kymograph curves for J. M., April 4, 1913.

With the infant E. N., three periods with an activity of I were secured in sequence on May 26, 1913 (see figure 52). The pulse-rate in the period I from 3h 21m p. m. to 3h 41m p. m. was 104 and the carbon-

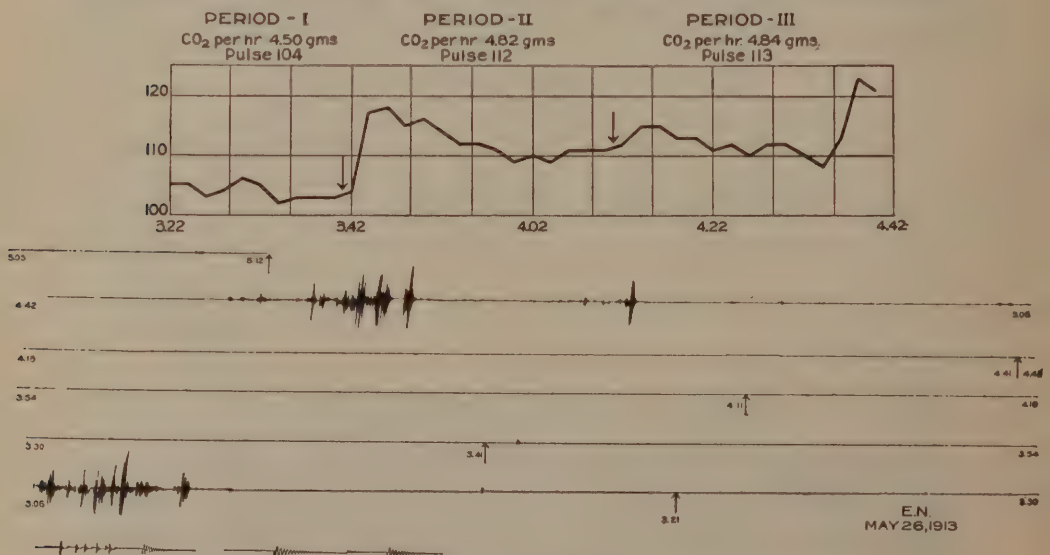

FIG. 52. Pulse-rate and kymograph curves for E. N., May 26, 1913.

dioxide output per hour was 4.50 grams. In the next two periods, the pulse-rates were 112 and 113 respectively and the carbon-dioxide production 4.82 grams and 4.84 grams respectively, showing the usual harmony.

This evidence of the relationship between the pulse-rate and the metabolism, taken in connection with the evidence presented in previous sections of this book, gives an entirely new significance to the pulse-rate, since it may be considered as a very fair index of the metabolism. In other words, an infant having a pulse-rate of 120 at one period of the day and of 150 at another period has unquestionably a greater metabolism in the second period. There is no evidence, however, that a difference in the pulse-rate of any two infants necessarily indicates a proportional difference in the metabolism, even though the infants be of the same weight and age, and the periods of observation of the same length. But it is safe to say that variations in the pulse-rate of an infant indicate a similar change in the metabolism.

It is not to be inferred that we believe that the increase in metabolism noted with increased pulse-rate is due exclusively to the mere mechanical work of circulation, as this is far from our belief. We especially wish to emphasize the fact that we look upon pulse-rate as an index of muscle or general tonus in the body and not as referring solely to the work of the heart muscles.

We may state, therefore, that whatever increases the pulse-rate also increases the katabolism, so that when the pulse-rate is elevated by the muscular activity incidental to restlessness, playfulness, laughing, or crying, or pathologically as in fever, we have every evidence that the katabolism is likewise increased and a larger proportion of food material or body substance is being consumed.

BASAL METABOLISM OF INFANTS STUDIED.

In beginning this research upon infant metabolism, one of the fundamental questions which presented itself to us with special force was as to what may be considered the normal basal metabolism of infants. Consequently we made it our aim to study as many infants as possible and to secure a sufficient number of periods of complete repose on a sufficient number of days to establish beyond reasonable doubt the basal metabolism of each infant. The infants secured for these observations varied sufficiently in age, weight, height, and sex to permit a comparative study of the results as to the constancy or lack of constancy in the metabolism.

SELECTION OF DATA USED FOR COMPARISON.

From the data obtained a table has been compiled which gives the average result of the periods with each infant in which the metabolism was at a minimum (see table 31). The selection of the periods was based upon the records of the pulse-rate and the muscular activity, only such periods being used as showed a normally low pulse-rate and practically no muscular activity, *i. e.*, those characterized as I or II. The figures for the ages and weights are the average ages and weights for the experiments included in the table. The data are arranged according to the increasing weights of the infants. Since with one

TABLE 31.—*Minimum metabolism of infants.*

Subject.	Sex.	Body-weight without clothing.	Height.	Age.	Days included in average.	Periods averaged.	Carbon-dioxide per sq. meter (Meeh) per hour.[1]	Oxygen per sq. meter (Meeh) per hour.
		kilos.	*cm.*	*mos.*			*gm.*	*gm.*
J. V.	F	1.94	47	3½	2	3	12.1	10.8
E. H. S.	M	2.96	51	3½	5	8	11.6	9.6
A. C.	F	2.99	..	1½	3	8	9.7	8.0
E. S.	F	2.99	..	5	3	6	14.0	11.0
A. D.	F	3.16	56	4½	5	15	13.0	10.7
K. R.	M	3.17	56	4	2	4	12.1	10.2
A. L.	F	3.18	53	4	2	2	12.4	10.7
L. O.	M	3.18	..	6	7	12	15.3	12.1
J. B.	M	3.23	..	5	2	4	13.3	10.2
G. S.	M	3.30	..	2½	3	5	12.1	10.0
J. V.	F	3.38	53	8½	3	3	16.7	13.4
F. M.	M	3.65	..	4½	3	5	15.4	13.0
M. D.	M	3.99	..	17 days	2	4	9.2	8.2
L. B.	F	4.04	..	4	3	8	13.2	10.6
E. L.	M	4.15	59	4	1	2	14.0	12.3
W. P.	M	4.31	..	5	2	6	14.6	11.6
J. S.	M	4.41	63	5½	5	7	15.6	11.9
E. R.	M	4.49	55	3	3	5	12.0	11.0
F. B.	M	4.87	60	5½	4	13	15.7	13.1
R. E.	M	5.04	60	4½	3	7	12.2	11.3
D. M.	M	5.18	66	11	2	2	15.0	12.5
D. Q.	M	5.28	62	4½	2	4	11.9	10.1
E. N.	F	5.40	66	6	7	22	13.9	11.7
J. P.	M	5.45	63	7	4	7	15.3	13.0
M. M.	F	5.47	62	4½	3	7	10.6	9.7
J. M.	M	5.63	62	8	2	6	18.2	15.1
M. A.	M	5.67	68	9	4	9	12.9	11.7
F. K.	M	5.71	65	7	6	8	14.2	12.6
L. R. B.	F	5.99	64	4	4	11	11.3	10.4
A. S.	M	6.02	63 ?	3	1	1	10.6	9.5
M. C.	F	6.17	63	4	3	7	11.9	10.1
P. S.	M	6.80	67	12	3	10	14.4	13.3
E. F.	M	7.07	62	3	2	2[2]	10.2	8.7
P. W.	M	7.11	64 ?	7	2	5	14.2	12.2
R. L.	M	7.58	71	8½	5	8	13.9	12.2
E. K.	M	8.03	73	17	1	2	14.2	12.9
H. T.	M	9.33	75 ?	5½	1	1	12.4	9.5
E. G.	M	9.37	74	10	3	5	11.4	11.4

[1]In accordance with the usage of Continental writers, we give these values, although we believe they are peculiarly liable to misunderstanding, and hence their use is unfortunate.
[2]The activity estimated for these two periods was II and III, respectively.

infant, J. V., the studies continued over a period of several months, the average minimum metabolism is given for periods secured at an early age, and again for periods obtained several months later. Various bases of comparison may be used, but in this table the infants have been compared on the basis of the energy transformation in 24 hours.

In employing the data in table 31 for the discussion of the fundamental questions considered, it is necessary to emphasize the fact that the amount of material and the method of its selection justify its use for a basis of comparison. The number of infants, *i. e.*, 37 in all, permits extended comparison and discussion.

TABLE 31—Continued.

Subject.	Heat produced. Per 24 hours.	Per kilogram per 24 hours.	Per square meter per 24 hours. Howland.[1]	Lissauer $10.3\sqrt[3/2]{W}$.	Meeh $11.9\sqrt[3/2]{W}$.	Average rectal temperature.[2]	Pulse-rate.
	cals.	*cals.*	*cals.*	*cals.*	*cals.*	*°C. (°F.)*	
J. V.......	164	85	984	1032	882	....	129
E. H. S....	194	65	891	906	783	36.8(98.2)	109
A. C.......	163	55	756	759	660	37.2(98.9)	126
E. S.......	225	75	1036	1048	911	36.5(97.7)	107
A. D.......	229	72	1010	1026	895	36.5(97.7)	114
K. R.......	213	67	936	960	829	36.6(97.8)	103
A. L.......	226	71	996	1020	876	36.8(98.3)	107
L. O.......	260	82	1154	1172	1008	36.9(98.5)	106
J. B.......	223	69	978	996	854	36.1(97.0)	95
G. S.......	216	65	931	946	818	36.9(98.4)	119
J. V.......	297	88	1264	1280	1108	37.3(99.1)	126
F. M.......	300	83	1219	1238	1064	37.1(98.8)	118
M. D.......	196	49	738	756	656	37.0(98.6)	127
L. B.......	272	67	1020	1041	901	36.9(98.5)	124
E. L.......	306	74	1128	1152	995	37.2(99.0)	127
W. P.......	303	70	1076	1104	962	36.8(98.2)	96
J. S.......	319	72	1114	1152	997	36.9(98.5)	111
E. R.......	283	63	979	1013	873	37.2(98.9)	116
F. B.......	370	77	1211	1257	1082	37.2(98.9)	111
R. E.......	324	64	1035	1070	919	37.1(98.7)	114
D. M.......	369	71	1152	1188	1034	37.3(99.1)	119
D. Q.......	305	57	930	972	846	37.3(99.1)	101
E. N.......	353	66	1069	1117	962	37.1(98.7)	111
J. P.......	387	70	1152	1207	1039	36.8(98.3)	105
M. M.......	285	52	854	891	770	36.8(98.2)	96
J. M.......	467	83	1368	1432	1239	37.2(98.9)	112
M. A.......	356	63	1037	1085	939	36.9(98.5)	105
F. K.......	381	67	1107	1158	1003	37.2(98.9)	109
L. R. B....	331	55	923	973	844	37.2(99.0)	106
A. S.......	305	51	840	888	774	37.3(99.1)	113
M. C.......	333	54	912	967	837	37.1(98.8)	103
P. S.......	453	66	1133	1219	1058	36.8(98.2)	100
E. F.......	311	44	756	828	708	37.1(98.8)	111
P. W.......	439	62	1061	1147	998	37.1(98.8)	120
R. L.......	455	59	1038	1140	991	37.4(99.4)	115
E. K.......	497	62	1092	1212	1044	37.7(99.9)	105
H. T.......	420	45	816	912	797	37.2(98.9)	101
E. G.......	479	51	922	1046	907	37.2(98.9)	106

[1]See p. 22. [2]During respiration periods.

Furthermore, the data are sufficiently extensive for each subject, as an examination of the table will show that, in all but two instances, at least two periods are used for securing the average value for each infant; in other words, the values were determined in duplicate. In many cases the number of periods for comparison greatly exceeded this; for example, in one instance 22 periods were available for averaging. The values for two infants, A. S. and H. T., are each based upon only one period and unfortunately these two are among the relatively few infants not under weight. We believe, however, that the probable accuracy of these periods is supplemented by a careful examination of other periods with these infants in which the metabolism accompanying the varying degrees of restlessness and activity was measured. Under the circumstances we do not feel justified in excluding these values from the table, although it is to be noted that in all of the subsequent discussion they may readily be omitted without in any way affecting the general inferences drawn from the research.

Obviously no infant lives on a minimum metabolic plane throughout the entire 24 hours; indeed, but a small proportion of the total number of the experimental periods could be utilized for this important comparative study. Nevertheless, since in but two instances was it necessary for us to rely upon the computation of the minimum metabolism of the infant from one experimental period, and in only one other instance were our data limited to those secured in two periods on one day, we believe that we have obtained a reasonably accurate estimate of the minimum metabolism of each infant, which justifies critical study and comparison.

Minimum Extraneous Muscular Activity.

In the previous discussion of basal metabolism,[1] we pointed out that this term is applied to the minimum metabolism of an infant, unaffected by extraneous muscular activity, and that it is probably best secured a number of hours after the last meal, when the infant is lying perfectly quiet, preferably asleep. It should here be emphasized that the discussion of table 31 and the charts in figures 53 to 65 are based upon this minimum basal metabolism.

As the investigation progressed, however, and the intimate relationship between pulse and muscular activity[2] became apparent, we found ourselves compelled to utilize the pulse records intelligently as an important adjunct in determining the minimum metabolism. Any effort to quantify the kymograph curves which were other than straight lines was obviously very difficult, for a break in the straight line caused by a variation of the pointer over 11 mm. might signify one gross movement, while a number of very small breaks with a sum of 20 or 30 mm. need have no such definite mathematical relationship to the heat-production. On the other hand, when the pulse-rate was per-

[1]See p. 30. [2]See p. 118.

sistently low, even periods with kymograph records which were not obviously straight lines could logically be used. So extraordinarily sensitive was the tambour and suspended crib system that the slight fluctuation which would be characterized, for example, as activity II, if unaccompanied by an increase in the pulse-rate, showed almost invariably no effect upon the metabolism. In a relatively few instances a kymograph curve that might be classified as III or between II and III was likewise unaccompanied by an increase in the pulse-rate and corresponded to a low metabolism period. While in general, therefore, the results are drawn from periods of absolute repose as indicated by the kymograph records, we have felt perfectly justified in including periods with activity II and rarely III, if they were accompanied by low minimum pulse-rates and a low metabolism. Such a selection was especially fitting, inasmuch as the average minimum metabolism of each infant was sought and the data are nearly always drawn not from a single isolated period, but from many periods, usually obtained on a number of days.

Occasionally an extraordinarily low value for the heat-production as computed indirectly was found for a single period. This low value was never included in the periods averaged for the minimum metabolism, as we believed it could be easily traced to an error in weighing the carbon-dioxide absorbers, or to some error in technique pertaining to the individual period. An examination of table 23 will show that these very low values were rare, being found possibly 4 or 5 times during the experimenting of a whole winter. It will be seen, therefore, that care was taken with every infant to secure the minimum value, knowing that ultimately several important comparisons would be made. All the information necessary for the use of investigators in making computations by any other method than those here suggested is given in table 23.[1] The data in this statistical table can be used with confidence, although we have not thought it wise to reject arbitrarily the very low values found in isolated periods. We firmly believe, however, that these were due to some discrepancy which unavoidably crept into the technique and a careful inspection of the data will show that they should not be employed in drawing average values.

Minimum Influence of Food.

In discussing our results, the criticism can be raised that one of the factors outlined in our definition of basal minimum metabolism was not as strictly observed in this study as could be desired, since the infants were rarely in the post-absorptive state, the observations being made for the most part from 1 to $1\frac{1}{2}$ hours after the ingestion of food.

It has clearly been shown in experiments on men and animals that the ingestion of a mixed diet results in an increased metabolism.

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[1] See p. 84.

When isolated nutrients are ingested, the greatest increase has been observed with protein. With fat there is relatively but little, if any, increase. With carbohydrates, while investigators differ as to the quantitative relationships, it has been observed with men in this laboratory that cane sugar and levulose may stimulate the metabolism to a degree comparable with that resulting from the ingestion of an equivalent weight of protein. On the other hand, lactose—the chief carbohydrate in the diet of infants—has a minimum influence upon the metabolism.

This criticism of our experiments has, therefore, considerable theoretical importance, but practically we must consider the fact that the diet of the infant is of such a character as to produce a minimum amount of increase in the metabolism. With infants a large proportion of the protein ingested—some 60 per cent or more—may be stored in the body, and Rubner has shown that this storage does not affect the total metabolism. Since the protein ingested by the infant rarely exceeds 15 per cent of the total energy requirement of the body,[1] it can be seen that we may expect from this nutrient only the minimum influence upon the heat-production of infants. Fat has admittedly but a slight influence, while the predominating carbohydrate—milk sugar or lactose—has likewise only a minimum influence.

On these grounds, therefore, one would conclude that the total nourishment of the infant consists of material which for the most part does not tend to stimulate the metabolism greatly. On the other hand, so keen an observer as Schlossmann[2] states that the effect of the ingestion of food probably persists for some 18 hours. Practically all of the investigators in metabolism have concluded that with adults, unless the diet is abnormally rich in protein, the metabolism reaches the basal line 12 hours after the last meal.

In our studies while it was impracticable to secure the metabolism on all of the infants 18 hours after the last meal, an effort was made to find out the length of time required to obtain the minimum basal metabolism after feeding milk. To this end some five or six infants were studied 1, $2\frac{1}{2}$, 5, 9, 12, 18, and 21 hours after food. The difficulties in securing ideal periods of rest exactly coincident with definite periods of time after the ingestion of food are sufficiently obvious to need no special comment here; it is only necessary to state that our evidence is admittedly not so complete as we should like. A critical examination of the data shows us, however, that on the whole the influence of milk feeding upon the metabolism of infants must be very slight. In certain instances the metabolism during quiet periods immediately after feeding is 5 to 10 per cent higher than 18 to 21 hours after, while in others the metabolism 21 hours afterward, even in periods of com-

[1]Rubner, Sitzber. K. Preuss. Akad. Wiss., 1911, **20**, pp. 440–457.
[2]Schlossmann, Atrophie u. respiratorischer Stoffwechsel, Kassowitz Festschrift, Berlin, 1912, p. 318.

plete muscular repose, was slightly greater than immediately after feeding. But the general picture derived from these observations indicates that the ingestion of milk played a very slight rôle, if any, in affecting the heat-production of the infants studied.

Recent observations in this laboratory during a 31-day fast showed that, as soon as food was completely withheld, the body storage of glycogen was rapidly drawn upon and a distinct acidosis appeared when it was exhausted. Our experience with diabetics and with normal individuals subsisting upon a carbohydrate-free diet[1] gives evidence that such an acidosis tends to increase the basal metabolism. Additional light has been thrown upon this subject by Schlossmann and Murschhauser[2] who have shown in a recent publication the influence of the withdrawal of food upon the excretion by infants of products of acidosis, particularly acetone, diacetic acid, and β-oxybutyric acid. Even in the first 24 hours of fasting, definite evidence of the excretion of β-oxybutyric acid shows the beginning acidosis. Knowing, as we do, that acidosis strongly tends to increase the metabolism, one sees instantly that a point or a moment when the influence of the previously ingested food ceases and the influence of an oncoming, though slight, acidosis begins, is extremely difficult to foretell, with our present knowledge. It should not be overlooked, however, that Schlossmann and Murschhauser did not find an increased heat-production in these infants showing incipient acidosis although we are inclined to doubt the validity of drawing conclusions regarding so subtle a factor as acidosis from periods with such changes in the degree of repose.

While, therefore, we recognize clearly that the presence of food in the alimentary tract of our infants has distinct theoretical objections, we believe that such influence, if it exist, can play no quantitative rôle in the striking comparisons of the basal metabolism of different infants which are made in the subsequent pages.

NORMALITY OF INFANTS STUDIED.

In carrying out this study of infant metabolism, we found ourselves immediately confronted by the difficulty of determining what is the normal infant. An inspection of the data supplied by Holt,[3] Heubner,[4] Camerer,[5] Gundobin,[6] and Sutils[7] shows noticeable variations in the normal weight of infants of different nationalities—variations that may easily amount in the earlier months to 5 or 8 per cent, even for a carefully selected, healthy, breast-fed infant. Our infants were usually bottle-fed and for the most part were under the normal weight. To show as

[1]Benedict and Joslin, Carnegie Inst. Wash. Pub. No. 176, 1912, p. 134.
[2]Schlossmann and Murschhauser, Biochem. Ztschr., 1913, **56**, p. 396.
[3]Holt, Diseases of infancy and childhood. New York and London, 6th ed., 1911.
[4]Heubner, Lehrbuch Kinderheilkunde, 3d ed., Leipsic, 1911, **1**, p. 7.
[5]Camerer, Der Stoffwechsels des Kindes, Tubingen, 1896.
[6]Gundobin, Die Besonderheiten des Kindesalters, Berlin, 1912.
[7]Sutils, Guide pratique du pesage pendant les deux premières années, Paris, 1889.

clearly as possible the variations between the weights of the infants included in this study and the accepted normal weights of infants of similar ages, we give in table 32, first, the age; second, the weights of our infants at the time of observation; and third, the average weight for infants of the ages indicated, these averages being compiled from

TABLE 32.—*Normal and expected body-weight of infants included in these observations.*

Subject.	Sex.	Age.	Height.	Body-weight without clothing.	Normal weight for age.	Expected weight.[1]
		mos.	*cms.*	*kilos.*	*kilos.*	*kilos.*
J. V.	Female	3½	47	1.94	5.90	3.95
E. H. S.	Male	3½	51	2.96	5.90	5.68
A. C.	Female	1½	..	2.99	4.30	3.99
E. S.	Female	5	..	2.99	6.82	5.35
A. D.	Female	4½	56	3.16	6.50	5.46
K. R.	Male	4	56	3.17	6.25	7.40
A. L.	Female	4	53	3.18	6.25	6.49
L. O.	Male	6	..	3.18	7.27	7.62
J. B.	Male	5	..	3.23	6.82	....
G. S.	Male	2½	..	3.30	5.16	5.40
J. V.	Female	8½	53	3.38	8.28	6.33
F. M.	Male	4½	..	3.65	6.50	....
M. D.	Male	17 days	..	3.99	3.60	....
L. B.	Female	4	..	4.04	6.25	6.71
E. L.	Male	4	59	4.15	6.25	....
W. P.	Male	5	..	4.31	6.82	6.15
J. S.	Male	5½	63	4.41	7.10	8.70
E. R.	Male	3	55	4.49	5.56	5.11
F. B.	Male	5½	60	4.87	7.10	8.24
R. E.	Male	4½	60	5.04	6.50	5.37
D. M.	Male	11	66	5.18	9.20	8.80
D. Q.	Male	4½	62	5.28	6.50	5.60
E. N.	Female	6	66	5.40	7.27	....
J. P.	Male	7	63	5.45	7.73	6.38
M. M.	Female	4½	62	5.47	6.50	6.28
J. M.	Male	8	62	5.63	8.07	....
M. A.	Male	9	68	5.67	8.49	8.84
F. K.	Male	7	65	5.71	7.73	7.87
L. R. B.	Female	4	64	5.99	6.25	6.93
A. S.	Male	3	63 ?	6.02	5.56	5.91
M. C.	Female	4	63	6.17	6.25	6.93
P. S.	Male	12	67	6.80	9.55	....
E. F.	Male	3	62	7.07	5.56	6.38
P. W.	Male	7	64 ?	7.11	7.73	....
R. L.	Male	8½	71	7.58	8.28	7.15
E. K.	Male	17	73	8.03	....	....
H. T.	Male	5½	75 ?	9.33	7.10	....
E. G.	Male	10	74	9.37	8.75	8.98

[1]Calculated by adding to or subtracting from the normal weight for age the excess or deficiency in weight at birth, assuming normal birth-weight as 3.40 kilograms and that increase in weight after birth is the same as for normal development.

Holt's table for healthy, American, breast-fed infants. Even with normal infants there are great differences in the birth-weight; we have accordingly computed for this table the weight that would be expected for each of our subjects with a normal rate of growth, taking into consideration variations in birth-weight and using the curve for

average weight of infants given by Holt.[1] (See table 33.) For example, if the infant weighed 0.5 kilogram more than the average weight at birth and we wished to know what it would have weighed at 5 months had it developed in the usual way, we added 0.5 kilogram to 6.82 kilograms (the average weight for this age as recorded by Holt) and considered 7.32 kilograms the weight that the infant would have weighed had it developed normally. The same procedure was followed if the infant was under weight.

TABLE 33.—*Average weights of American infants (Holt).*

Age.	Weight.	Age.	Weight.
mos.	*kilos.*	*mos.*	*kilos.*
Birth...	3.409	7......	7.727
1.......	3.860	8......	8.070
2.......	4.770	9......	8.390
3.......	5.560	10......	8.750
4.......	6.250	11......	9.200
5.......	6.818	12......	9.545
6.......	7.270		

It is clear that relatively few of the infants included in our study can be considered of normal weight, that is, the average weight of healthy infants, as only 8 out of the 37 reported are equal to or exceed the normal weight; one of the infants, H. T., is considerably above the normal weight. It is understood, then, that we are considering for the most part infants that are under weight. Certain of these were in the subnormal temperature stage of infantile atrophy; others were in the repair stage and with normal temperature.

The term "infantile atrophy" is applied to an emaciated infant with such severe indigestion that it is unable to digest weak mixtures of cow's milk, with no gain in weight, and with a subnormal body-temperature. The convalescent stage of infantile atrophy is that in which the same infant subsequently begins to digest its food and to gain weight, and has a normal temperature. Under-weight infants are those who are 0.5 kilogram or more below the average weight for their respective ages but whose digestion is not so severely deranged as those with infantile atrophy. This group includes all infants not classified as normal, or with infantile atrophy, or in the convalescent stage of infantile atrophy.

RELATIONSHIP BETWEEN BODY-WEIGHT AND METABOLISM.

One of the two factors commonly referred to as exercising a most pronounced influence upon the total metabolism is the body-weight. Charts have therefore been prepared in which comparisons have been made between the body-weights of our infants and the heat-production.

[1]We recognize that there is no absolutely definite normal weight that can be established for all infants. The charts of growth given by the various authorities are all very similar, their differences being explained by the fact that they often represent infants of different nationalities or of different social and hygienic surroundings. Since the charts usually represent average and not normal infants, it is very difficult to apply the test of normal or abnormal weight to any given infant. Therefore, in comparing the infants used in this investigation, both the average and the estimated weights will be considered. Hereafter we shall use the term "normal weight" as meaning the average weight. The average weights of American infants are given in table 33, which is taken from Holt (*loc. cit.*, p. 17), who made it up from the records of 100 healthy nursing infants and the incomplete weight charts of about 300 other infants.

COMPARISON OF THE BODY-WEIGHT OF INFANTS AND THE TOTAL HEAT-PRODUCTION IN 24 HOURS.

A chart comparing the body-weight of our infants with their total heat-production in 24 hours is given in figure 53.

In general one would expect that a large animal would give forth more heat than a small animal, and an inspection of this chart shows that for the most part those infants with the larger body-weight have a larger heat-production. On the other hand, it will be seen that the

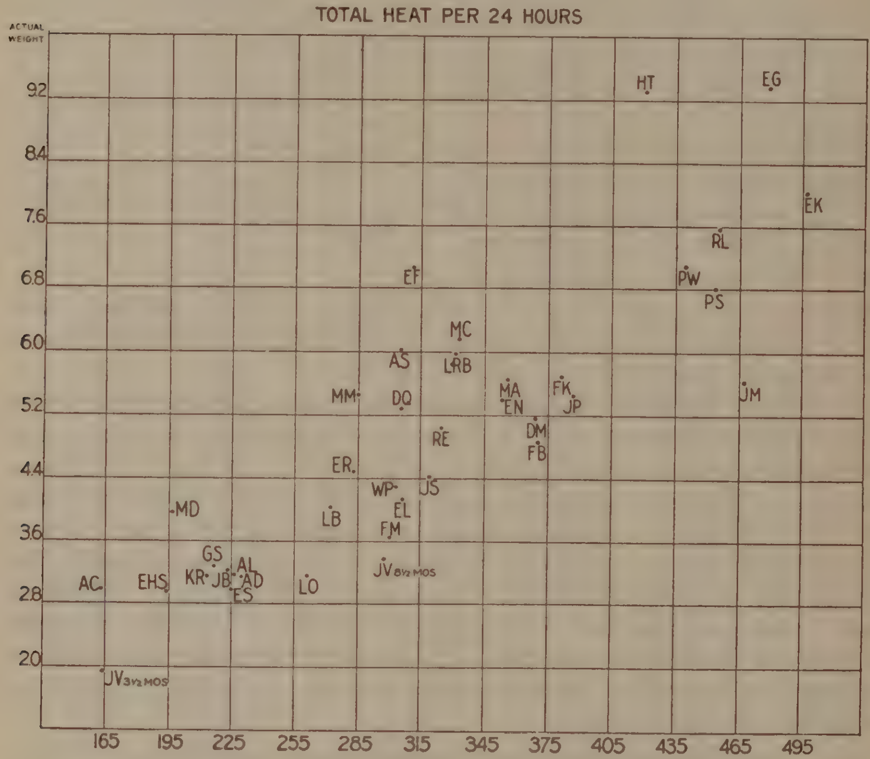

FIG. 53. Chart showing actual body-weight of infants and total heat-production per 24 hours.

values by no means lie in a straight line, possibly the most striking exception being J. M., with a body-weight of 5.6 kilograms and a heat-production of 467 calories. It is clear from this chart, therefore, that while in general the larger infants show the larger heat-production, this is by no means invariably the case, and a definite rule, based solely upon body-weight, can not here be established.[1]

It is obvious that the composition of the body must play a considerable rôle. Those tissues most active in the metabolic processes—the

[1]By selecting the "normal" infants, a straight line is approximated. Recently determined values on other infants of normal weight indicate considerable regularity in the curve.

muscles and organs of circulation—must have a greater metabolism than the integument, hair, finger nails, etc.; thus, with a larger proportion of active protoplasmic tissue in a body, a greater heat-production would normally be expected. On the other hand, inert adipose tissue, even if it be present in large amounts, would not be expected to contribute materially to the heat-production. Hence it would be logical to assume that heavy, fat infants need not necessarily have a greater total heat-production than infants of the same weight having less fat. Unfortunately, in the discussions of infant metabolism presented heretofore by the various writers, almost no consideration is given to the length[1] of the infant. An infant weighing 8 kilograms, 60 cm. long, has obviously a larger proportion of fatty tissue than an infant of the same weight but 70 cm. long, and on the basis of body-weight alone we should normally expect that the longer, thinner baby, with the smaller amount of fat, would have the larger heat-production.

As stated in the discussion of table 32 the infants included in our study were, for the most part, under weight. There would thus be a deficiency in fat, and possibly a deficiency in the active protoplasmic tissue, but all of the evidence points to the fact that a large part of the discrepancy in weight must have been due to a deficiency in fat. In considering our infants, it should be borne in mind that the actual body-weight on these or similar charts does not give the slightest indication as to the probable chemical composition of the body, particularly with regard to the proportion of fat or of active protoplasmic tissue. The great lack of uniformity in the total heat-production of 24 hours, when considered on the basis of body-weight, may, therefore, be considered as possibly explained by variations in the chemical composition of the bodies of the different infants, *i. e.*, in the relative proportions of fat and active protoplasmic tissue. Accordingly the chart in figure 53 is chiefly of interest as indicating in this group of infants, as a whole, that there is no definite uniformity between body-weight and total heat-production for 24 hours in infants under uniform conditions as to muscular activity and general repose.

HEAT-PRODUCTION PER KILOGRAM OF BODY-WEIGHT.

A method commonly used for the comparison of individuals of different body-weights is to compute the metabolism on the basis of per kilogram of body-weight. Thus differences in total metabolism ascribable to body-weight alone are eliminated. Accordingly in the chart in figure 54 we have presented the heat-production per kilogram

[1]In this connection it should be noted that owing to the stimulating suggestions of Rubner, great emphasis has been laid upon the computed body-surface of infants and its relation to the total metabolism. Aside from the formula of Miwa and Stoeltzner (Zeitschr. f. Biol., 1898, **36**, p. 314) for computing the body-surface of infants, all formulas, including those most extensively used at the present day, disregard completely the length of the infant in computing the body-surface, and the computation, therefore, rests upon a determination of the body-weight—the only measured value introduced into the formula.

of body-weight per 24 hours for all of our infants. An inspection of these points shows conclusively that there is no regularity in the values for the different infants. The heavy babies, H. T. and E. G., had a low energy transformation per kilogram of body-weight, but two very young infants, A. C. and M. D., had similarly low values, although in general the infants of the smallest body-weight have high values.

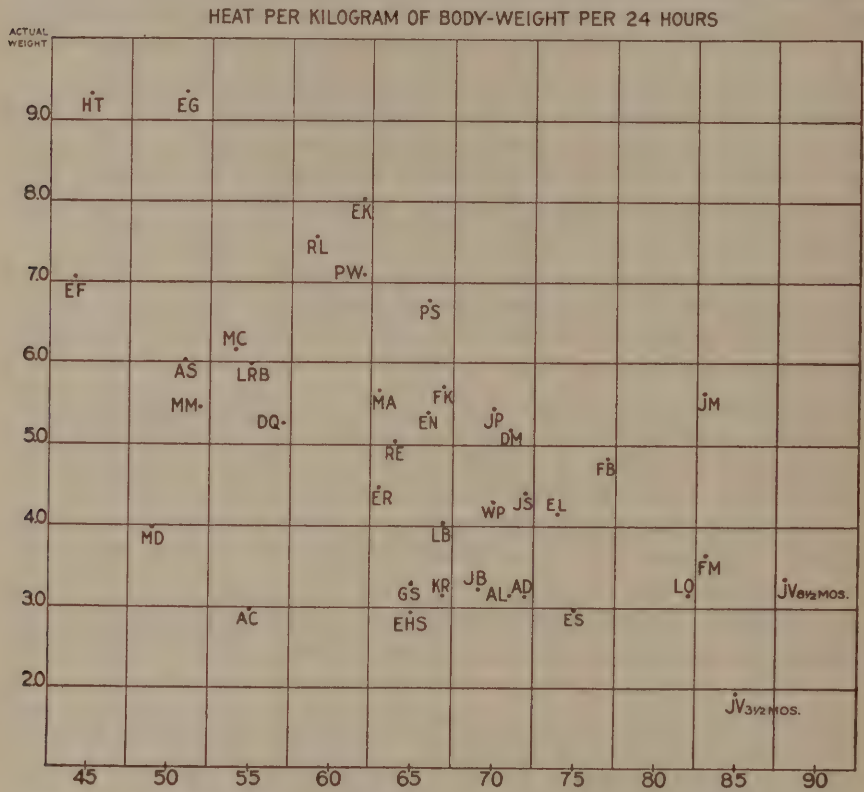

FIG. 54. Chart showing the actual body-weight of infants and the heat-production per kilogram of body-weight per 24 hours.

Thus it is seen that in comparing the metabolism of different infants we have to deal with some factor or factors other than body-weight. Inasmuch as the state of nutrition is not indicated by the records of the body-weight at the time of the observation, it is obviously impossible to discuss the influence of this factor simultaneously with the total body-weight without further data.

COMPARISON OF NORMAL BODY-WEIGHT AND TOTAL HEAT-PRODUCTION IN 24 HOURS.

Since the infants were mostly under weight, a comparison between the metabolism as measured and the normal weight of infants at the same age is justifiable and may prove suggestive in interpreting the

results. A chart has therefore been plotted (see figure 55) giving the total heat produced per 24 hours for the different infants and the average body-weight for a normal infant at the age when the metabolism was observed. Here again no special uniformity is seen, although in general those infants with the largest body-weight have the largest heat-production. On the other hand, with infants ranging from 6.3 to 7.3 kilograms, many instances were found when both very low heat-production and high heat-production are noticed.

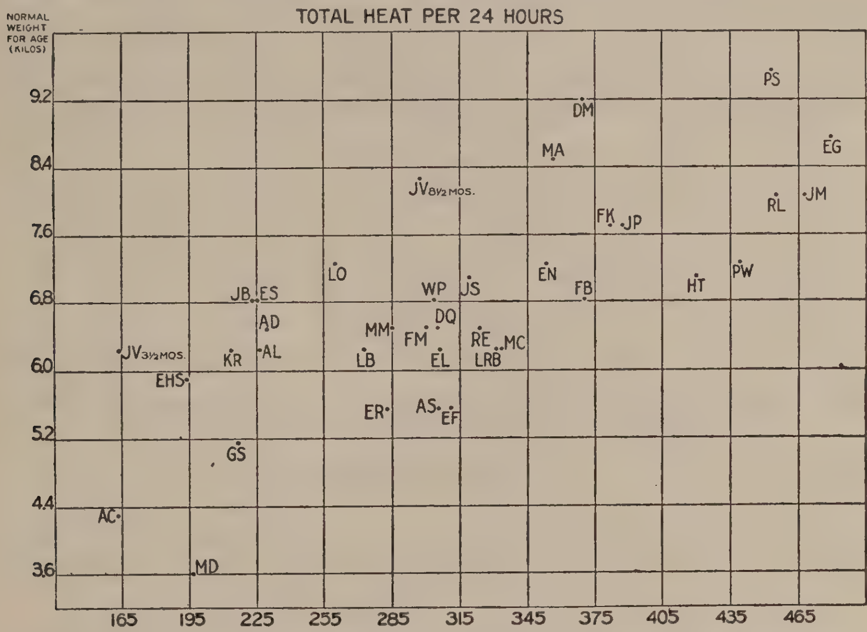

FIG. 55. Chart showing the normal weights for the ages of the infants under observation and the total heat-production per 24 hours.

COMPARISON OF NORMAL BODY-WEIGHT AND HEAT-PRODUCTION PER KILOGRAM OF ACTUAL BODY-WEIGHT.

In an attempt to reduce one factor in the comparison to a common basis, the values for the heat produced have been computed on the basis of per kilogram of body-weight, using the average weight for normal infants of the same age (see figure 56). No greater uniformity is apparent here than in the preceding charts and evidently no correlation can be found between the computed normal body-weight and total heat-production either on the basis of the total heat per 24 hours or the heat per kilogram of body-weight.

COMPARISON OF EXPECTED BODY-WEIGHT AND TOTAL HEAT-PRODUCTION IN 24 HOURS.

The average body-weights of healthy infants used in the foregoing comparisons are based upon the assumption that the infant was of normal weight at birth. Since the birth-weights of many of our infants

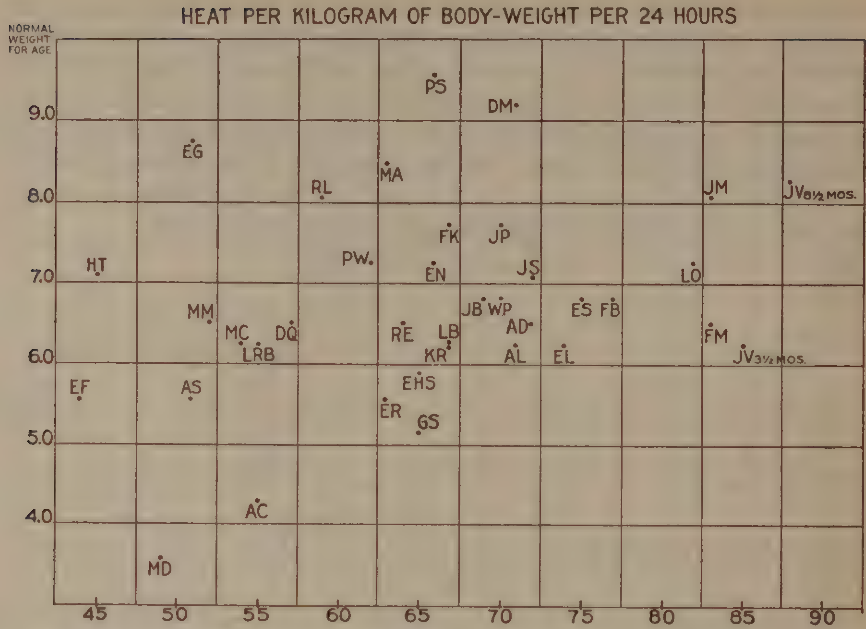

FIG. 56. Chart showing the normal weights for the ages of the infants under observation and the heat-production per kilogram of actual body-weight per 24 hours.

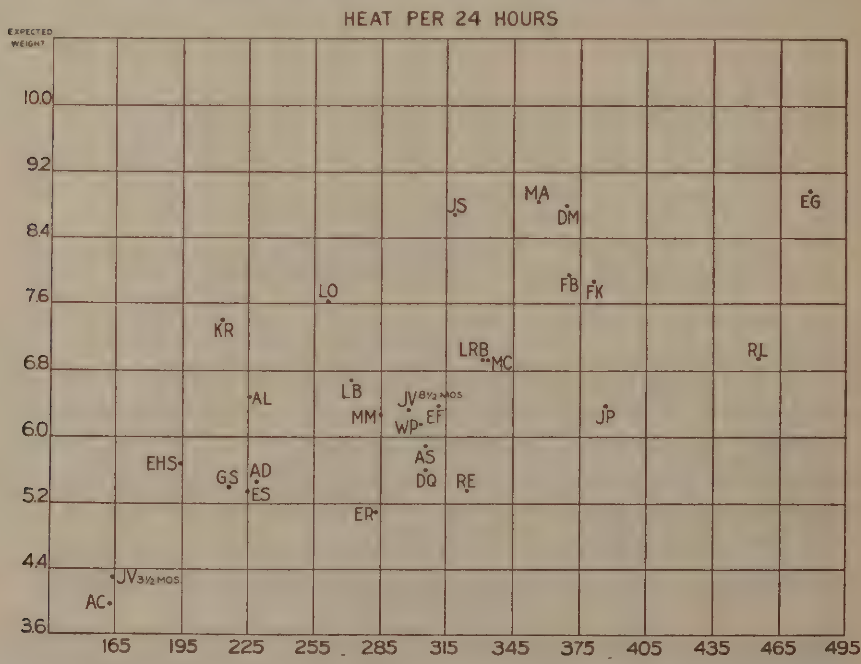

FIG. 57. Chart showing the expected weights for the infants under observation and the total heat-production per 24 hours.

are known to us, we computed the expected weight of our infants as explained on p. 148, thus taking into account any variation from the normal in birth-weight but assuming normal growth. These weights, which are given in the last column of table 32, are compared with the total heat-production in the chart in figure 57. As in all the foregoing comparisons, no regularity is apparent.

COMPARISON OF EXPECTED BODY-WEIGHT AND HEAT-PRODUCTION PER KILOGRAM OF ACTUAL BODY-WEIGHT.

We have plotted in the chart in figure 58 the values for the heat-production per kilogram of actual body-weight for 24 hours for those of our infants whose birth-weight was obtainable. The same absence of any tendency toward regularity in the chart is seen as in the foregoing com-

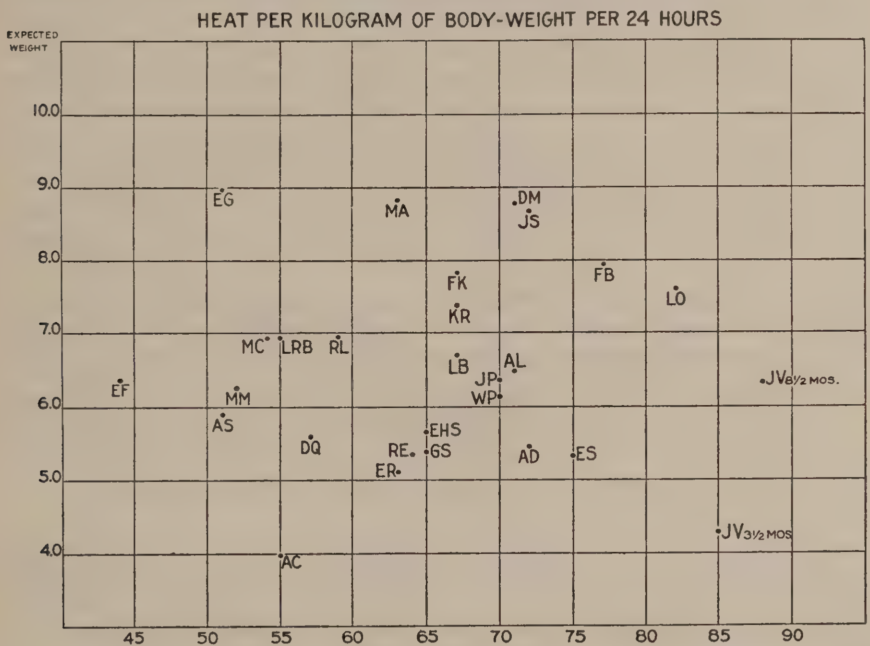

FIG. 58. Chart showing the expected weights for the infants under observation and the heat-production per kilogram of actual body-weight per 24 hours.

parisons. We may therefore conclude that, aside from a slight tendency for the total metabolism to be larger with increasing weight, no regular relationship exists with infants between the total heat-production and the body-weight, regardless of whether the body-weight was actually found, computed from statistics of average values for normal infants, or was the expected body-weight based upon the birth-weight. This lack of correlation is likewise seen when the heat-production per kilogram of body-weight for 24 hours is computed on the various weight bases. It is clear, then, that some factor other than the body-weight influences the heat-production.

COMPARISON OF THE AGE AND HEAT-PRODUCTION PER KILOGRAM OF BODY-WEIGHT.

Since an inspection of the data contained in table 31 appeared to show that the younger infants produced the least heat per 24 hours, it seemed desirable to study the influence of age upon the metabolism. A chart was prepared in which the heat per kilogram per 24 hours is compared with the age at the time of observation, this comparison being given in figure 59. Here again no correlation is indicated between the two factors, infants $4\frac{1}{2}$ months of age showing a heat-production per kilogram of body-weight ranging from 55 to 85 calories per kilogram per 24 hours.

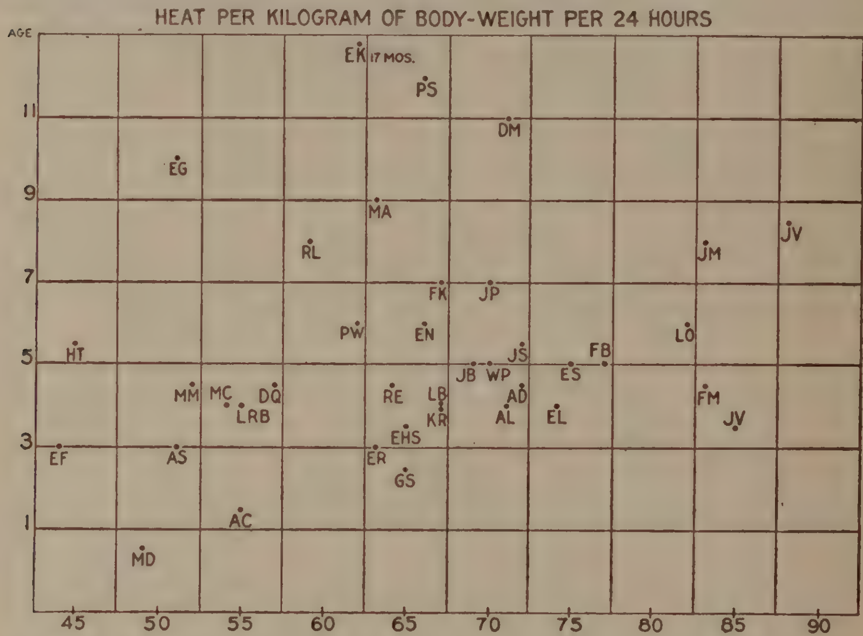

FIG. 59. Chart showing the age of infants and heat-production per kilogram of body-weight per 24 hours.

From these data, therefore, it would appear that neither the weight nor the age shows a uniform relation to the total heat-production or to the heat-production per kilogram of body-weight. In this finding we are completely in accord with all other experimenters in metabolism, since the lack of relationship between body-weight and metabolism is invariably noted. This is particularly the case when two living bodies are compared which vary considerably in weight.

With men, it is true, the metabolism per kilogram of body-weight is considered and commonly used as a reasonably accurate base-line for comparative purposes. Nevertheless the relationship is invariably disturbed when one of the individuals is very fat and the other under-

nourished, so that although the use of the base-line of per kilogram of body-weight may be justified when comparing individuals of average weight and approximately constant body composition, *i. e.*, with no great differences in the proportion of body-fat and muscular tissue, yet when comparing bodies of widely varying body-weight and body-composition, this basis of comparison can not be considered reliable.

RELATIONSHIP BETWEEN BODY-SURFACE AND METABOLISM.

For many years writers in metabolism have been wont to emphasize the significance of the relationship supposed to exist between the metabolism and the body-surface rather than that between the metabolism and the body-weight. The idea that there is an intimate relationship between body-surface and heat-production was first brought out by Bergmann[1] in 1847. The theory lay dormant for many years, but was finally resuscitated and put forth in a brilliant and highly stimulating manner by Rubner[2] in 1883, together with experimental evidence. Based fundamentally upon Newton's law of cooling, it received great attention from practically all workers in physiology. Startling evidence was brought forward to demonstrate that the heat-production per square meter of body-surface was about 1,000 calories for practically all species of animals, and this lent further support to the hypothesis. In connection with our own researches we naturally expected to find a close relationship between body-surface and total metabolism, particularly in view of the fact that recent observations from foreign laboratories appeared to confirm the validity of Rubner's law. We were therefore greatly surprised on preparing our final figures to find this intimate relationship entirely disturbed.

METHODS USED FOR MEASUREMENT OF BODY-SURFACE.

In order to discuss intelligently the relationship between the metabolism and body-surface, a critical examination of the various methods for determining the body-surface is essential. Using as a basis the relationship between the surface of similar solids which is expressed by the cube-root of the square of the weight, efforts have been made by a number of investigators to compute the body-surface of various animals and individuals from the body-weight.

Meeh[3] found that he could measure the body-surface of men by using the constant 12.312, which, when multiplied by the cube-root of the square of the body-weight in grams, gave the body-surface in square centimeters. Rubner and Heubner,[4] who first applied this formula to the study of the total metabolism of infants, rightly sub-

[1]Bergmann and Leuckart, Anatomisch-physiol. Uebersicht des Thierreichs. Stuttgart, 1852. p. 272. See also, Bergmann, Wärmeökonomie der Thiere. Göttingen, 1848, p. 9.
[2]Rubner, Zeitschr. f. Biol., 1883, **19**, p. 545.
[3]Meeh. Zeitschr. f. Biol. 1879, **15**, p. 425.
[4]Rubner and Heubner, Zeitschr. f. exp. Pathol. u. Therapie, 1904–1905, **1**, p. 1.

stituted the value 11.9 which was determined by Meeh on the two well-nourished infants under 1 year that he measured.

Recognizing the importance of considering the length of the body as well as the circumference of breast and abdomen, Miwa and Stoeltzner,[1] using Meeh's measurements, proposed another formula, in which the length and circumference as well as weight should appear as factors. This formula has not been generally accepted by research workers.

Actual measurements of the body-surface of cadavers have also been used in an attempt to find some mathematical formula expressing the relationship between body-weight and body-surface. Lissauer[2] measured 12 cadavers, 11 of which were under one year, and found that the constant 10.3 should be used in the Meeh formula instead of those previously proposed. It has been maintained by other writers that since many of Lissauer's measurements were made upon thin, poorly nourished, and atrophic infants, they do not give standards for well-nourished infants. Sytscheff[3] measured 10 infants under one year of age, but computed no ratios. Howland,[4] employing Meeh's and Lissauer's measurements, has recently proposed still another method for computing the body-surface based upon a curve represented by the algebraic formula $y=mx+b$.

With these three methods in vogue for computing the body-surface, *i. e.*, that of Rubner and Heubner using the Meeh formula with the constant 11.9; that of Lissauer using the constant 10.3; and that of Howland using the algebraic curve—it can be seen that, with the great weight laid by all experimenters in infant metabolism upon the relationship between body-surface and metabolism, it is incumbent upon us to present our results on the three separate bases, although the relative values remain unaltered in all three cases. This is done in table 31,[5] the plotted values being given in figures 60, 61, and 62.

COMPARISON OF AGE AND HEAT-PRODUCTION PER SQUARE METER OF BODY-SURFACE.

According to accepted ideas we should expect to find the heat-production per square meter approximately constant for all of our infants, *i. e.*, not far from 1,000 calories per square meter of body-surface. That this value is far from constant is seen clearly in table 31, but the variations are most strikingly shown if we compare them with the age of the infant, as is done in the charts in figures 60 to 62.

In the chart in figure 60, the range in heat-production per square meter of body-surface (Meeh formula) per 24 hours is very wide, the lowest value being 656 calories for M. D., and the highest 1,239 calories

[1]Miwa and Stoeltzner, Zeitschr. f. Biol. 1898, **36**, p. 314.
[2]Lissauer, Jahrb. f. Kinderheilk, 1902, **58**, p. 392.
[3]Sytscheff, Measure of volume and body-surface of children according to their ages. Dissertation, St. Petersburg, 1902. See, also Gundobin, *loc. cit.*, p. 54.
[4]See p. 22 for further explanation of this method.
[5]See p. 143.

for J. M. An inspection of the plot shows no average value, for even when we omit the extreme values for M. D., A. C., E. F., and J. M., the limits still remain 771 to 1,108. A larger number cluster around 875 calories, but there are too many scattering values to permit the use of 900 calories as an average value. If a line were drawn passing through the greatest number of points in this curve, it would indicate that there is a tendency for the older infants to have a higher heat-production, and yet, even with infants of the same age, wide variations are to be observed. This chart, therefore, leaves no doubt as to the lack of constancy in heat-production per unit of body-surface for the infants under observation in this research.

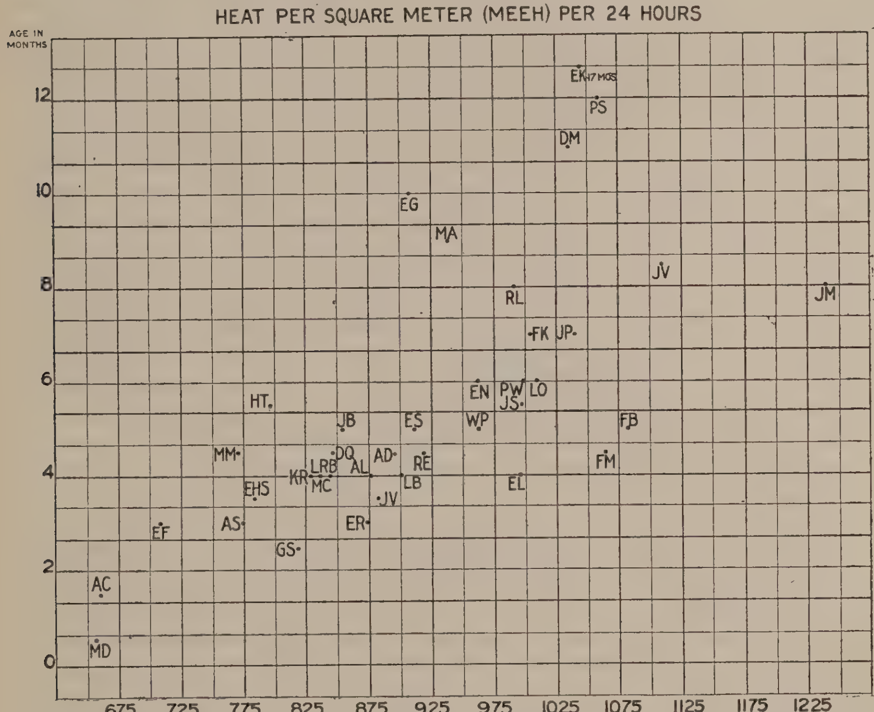

FIG. 60. Chart showing age of infants and heat-production per square meter of body-surface (Meeh formula) per 24 hours.

In the charts in figures 61 and 62, a comparison is made of the same two factors, using as a basis the Lissauer and Howland formulas respectively. The substitution by Lissauer of 10.3 for the constant 11.9 in the Meeh formula has not materially altered the picture as is shown by comparing the charts in figures 60 and 61. In the latter. the minimum value is 753 calories with M. D., and the maximum 1,432 calories with J. M., with a tendency for some of the points to collect about the value 1,025 calories. The plot in general can not be con-

sidered in any sense as indicating uniformity, although a slight general inclination is shown for older infants to have a higher heat-production on this basis.

With Howland's formula (see figure 62) the general picture presented is essentially the same. The lowest value on this basis is 739 calories with M. D., and the highest is 1,367 calories with J. M. The general tendency for the older infants to have a higher heat-production may again be inferred from an inspection of the chart in figure 62, though no definite regularity in the relationship between age and heat-production can be seen.

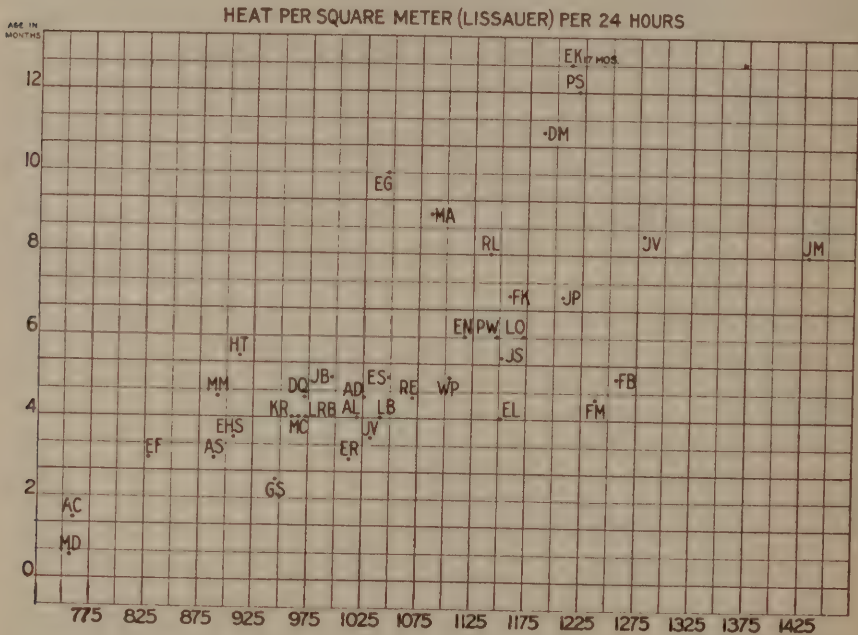

FIG. 61. Chart showing age of infants and heat-production per square meter of body-surface (Lissauer formula) per 24 hours.

It should be borne in mind that, according to the currently accepted views, the charts in figures 60, 61, and 62 should theoretically have been straight lines—that is, that the points should have grouped themselves more or less in a vertical manner. As a matter of fact, the grouping appears to be more horizontal than vertical, thus showing by a visualized method a complete absence of correlation in the heat-production per square meter of body-surface with infants of different ages.

With such large variations it was highly improbable that further comparisons on this basis would lead to any explanation of the discrepancies. Nevertheless, so at variance are these results that we have deemed it necessary to make all possible computations and comparisons

and to see if definite relationships can be established for the heat-production per square meter of body-surface and the age, weight, and length of the different infants.

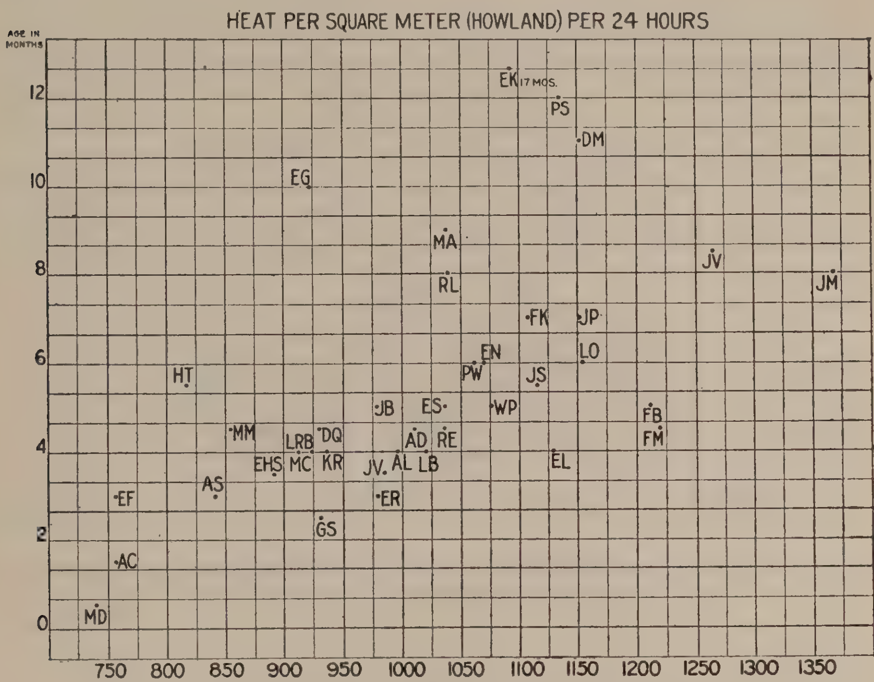

FIG. 62. Chart showing age of infants and heat-production per square meter of body-surface (Howland curve) per 24 hours.

COMPARISON OF ACTUAL BODY-WEIGHT AND HEAT-PRODUCTION PER SQUARE METER OF BODY-SURFACE.

In the charts in figures 63, 64, and 65, the heat-production per square meter of body-surface has been compared with the actual body-weight using the three formulas. In the chart on the Meeh formula given in figure 63, we should again expect according to current belief to find the values grouping themselves in a vertical line. On the contrary, the dispersion is even more marked than in the charts plotted on the basis of age, with a tendency, if any, toward a horizontal rather than a vertical alignment. The complete absence of correlation is here again strikingly shown, nor is the general picture of the relationship between actual body-weight and the heat-production per square meter of body-surface materially altered when the plots are made on the formula of Lissauer (figure 64) or on the formula of Howland (figure 65).

It is again important at this point to recall the fact that the observations made on these infants were all under constant conditions, namely, complete muscular repose and at approximately the same length of

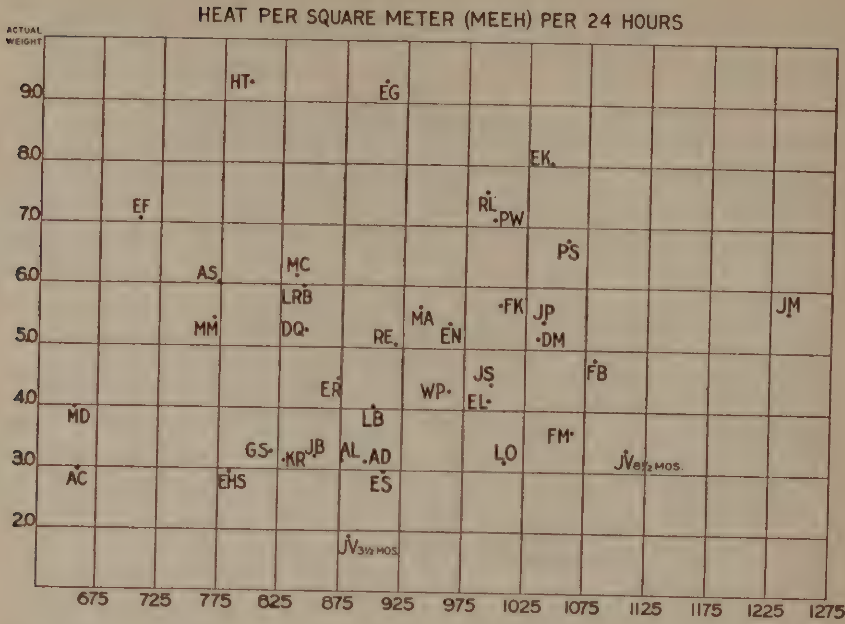

Fig. 63. Chart showing actual body-weight of infants and heat-production per square meter of body-surface (Meeh formula) per 24 hours.

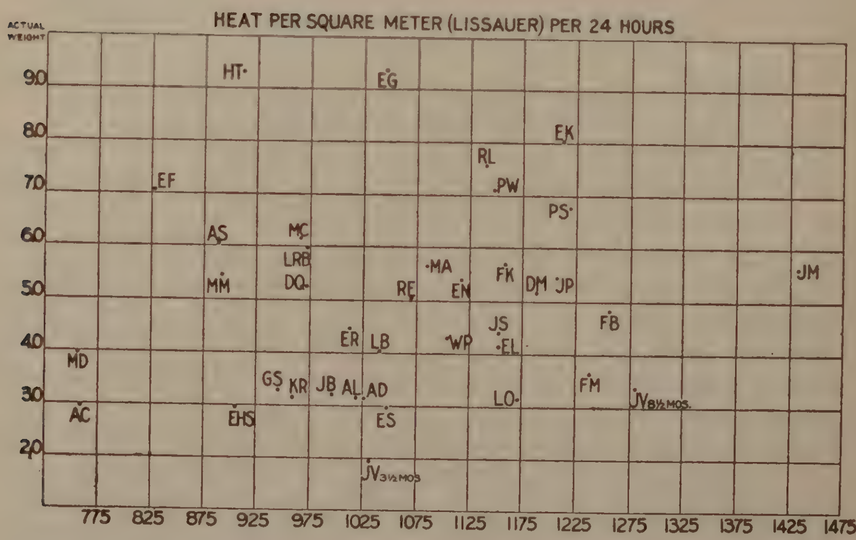

Fig. 64. Chart showing actual body-weight of infants and heat-production per square meter of body-surface (Lissauer formula) per 24 hours.

time after feeding. It is impossible, therefore, to explain these great discrepancies as being due to muscular activity, nor can they in any way be accounted for by the ingestion of food, since our experiments have shown that the food taken by these infants while under observation had no material influence upon the metabolism. Finally, it should be noted that, in general, the observations were made at substantially the same time relations to the food ingestion.

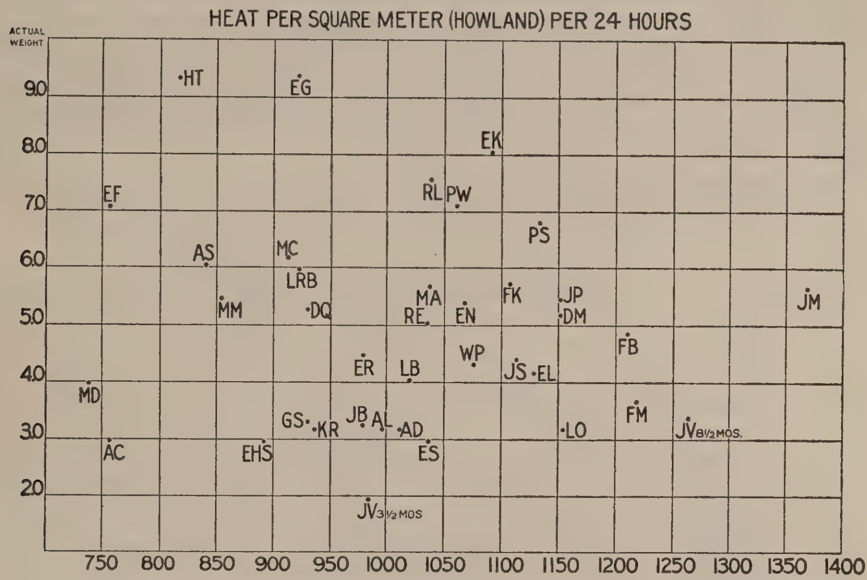

Fig. 65. Chart showing actual body-weight of infants and heat-production per square meter of body-surface (Howland curve) per 24 hours.

EFFECT ON METABOLISM OF POSSIBLE DISTURBANCE IN RELATIONSHIP BETWEEN BODY-SURFACE AND BODY-WEIGHT.

It has frequently been the custom when discrepancies in the heat-production per square meter of body-surface are found with infants, and particularly with atrophic infants, to ascribe the variation to a disturbance of the relationship between body-surface and the body-weight from which it is computed. It is essential, therefore, at this point to discuss this possibility more in detail.

The argument frequently raised is that disturbances in the relationship between body-weight and body-surface with under-weight infants precludes the use of any of the formulas now regularly used for the computing of body-surface, in that they give too small a value of body-surface for such infants. At the outset we wish to oppose this general thesis on the ground that in the most extensive and remarkably accurate series of measurements on infants with which we are familiar, namely, those of Lissauer, it is especially emphasized that 10 out of 12

of the infants were very much under weight. This will be seen by reference to table 34, which reproduces the weights of 11 of the infants measured by this investigator.[1]

As Lissauer himself points out with regret, S—i was the only case which could be called normal, although S—r was practically of normal weight. All of the other cases were noticeably under weight, far more so than our infants as a rule. Yet, in spite of this great deficiency in weight, the relationship between the body-weight and the measured body-surface was represented by the difference between the constant 10.3 used by Lissauer and 11.9, the constant of Meeh. In other words, this large variation in weight produced a maximum discrepancy of not over 15 per cent in the relationship between the body-surface as actually measured and the body-weight.

Table 34.—*Body-weights of infants measured for body-surface by Lissauer.*

Name.	Sex.	Age.	Body-weight.	Average weight for age obtained from Heubner.
			kilos.	*kilos.*
M—f.....	M	3½ mos.	3.27	6.2
H—r......	F	3½ "	1.96	6.2
R—e......	F	3¾ "	3.37	6.3
S—e......	M	1 "	2.22	4.008
S—r......	F	1 "	3.83	4.008
M–r......	M	15 "	5.23	11.+
W–t......	M	17 days	1.73	3.6
S–t.......	M	22 "	1.28	3.7
P—z......	M	3¼ mos.	2.50	6.0
H—z.....	M	7½ "	3.10	8.2
S—i......	M	3⅔ "	6.18	6.3

It is furthermore of interest to note, although this is probably a mere coincidence, that one infant, especially cited by Lissauer as a normal infant (S—i), gave a constant of 10.3. When one considers that the Meeh constant of 11.9 was based upon the measurements of but two infants less than a year old, it seems probable that the Lissauer formula is more nearly accurate and that the difference in the relation between body-weight and body-surface due to under weight is not appreciable. That the opposite is true, namely, that there is no disturbance in the relationsip between body-weight and body-surface when the infant is over weight, lacks, as yet, experimental evidence for confirmation or refutation.

The possibility of the disturbance in the relationship between body-surface and body-weight in under-nourished infants has been provided for in the presentation of our data, in that the comparisons have been made upon the three bases of Meeh, Lissauer, and Howland. We

[1]Lissauer, *loc. cit.*

frankly consider for our own work that the factor 10.3 which was most carefully determined by Lissauer is the one logically best adapted for use in computing the body-surface of the greater number of infants. We furthermore believe that Lissauer's formula would, in general, more nearly fit the requirements of observations in clinics, where the larger number of infants are under weight. On the other hand, as we have already pointed out, it is distinctly questionable whether the methods of measurement[1] have even yet been sufficiently refined or are sufficiently numerous to give a reliable method for the computation of the body-surface from the body-weight.

TABLE 35.—*Heat-production per square meter of body-surface (Meeh formula) for normal infants.*

Subject.	Body-weight without clothing.	Height.	Age.		Days.	Periods.	Heat per square meter of body-surface (Meeh).
	kilos.	*cm.*	*mos.*	*days.*			*cals.*
M. D.......	3.99	..	..	17	2	4	656
M. C.......	6.17	63	4	..	3	7	837
L. R. B.....	5.99	64	4	..	4	11	844
E. G.......	9.37	74	10	..	3	5	907
R. L.......	7.58	71	8½	..	5	8	991
P. W.......	7.11	64 ?	7	..	2	5	998

Although we believe that the lack of consistency exhibited by our infants in the heat-production per square meter of body-surface may not be ascribed to the fact that these infants were distinctly under the average weight, it is of special interest to select the relatively few infants who are of normal average weight and note the relationship between the heat-production and the body-surface. This has been done in table 35, in which the heat-production per square meter has been calculated for 6 of our normal infants of average weight.

In no case were less than 4 periods used for averaging, and usually the average was drawn from a larger number of periods, the range being from 4 to 11 periods. Even with these selected infants, the variations in the heat-production per square meter of body-surface range from 656 to 998 calories. It is thus evident that the disturbance noted with our whole collection of infants in the relationship between the heat-production and the body-surface is also apparent with selected infants having a normal or approximately normal average weight.

[1]As an interesting evidence of our initial belief in the importance and significance of the measurement of body-surface and its relationship to metabolism, we should here state that extensive preparations were made by us for the measurement of the body-surface of a number of infants, and a method was developed for securing shadow photographs of infants in various positions, the areas of the shadows being measured by a planimeter. It was our hope to establish thereby some relationship with the body-surface as measured from the shadow photograph, and by actual measurements of cadavers, and the body-weight and length. It is needless to say that with our present views in regard to the significance of body-surface in its relation to metabolism, we have not felt justified in continuing such a series of measurements.

INFLUENCE OF VARIATIONS IN THE COMPOSITION OF THE BODY UPON TOTAL HEAT-PRODUCTION.

Since a gross disturbance in the relationship existing between the body-weight and the body-surface as computed from the body-weight is highly improbable, whether the infant is atrophic or well nourished, it is important to find out, if possible, if any relationship exists between the general composition of the body and the total heat-production. Our data are sufficiently extended to permit a somewhat incomplete discussion of this important phase of the comparisons.

Heretofore, all workers in metabolism have considered only the relationship between body-weight and metabolism, or body-surface and metabolism. Since the body-surface is assumed to have a direct relationship to the body-weight, it can be seen that body-weight is the only fundamental factor which has thus far been seriously considered by investigators in comparing the metabolism of different infants.

It is obvious that when two infants are of the same weight, the shorter one will have the larger proportion of fat. Furthermore, with two infants of the same length but of different weights, the heavier infant will have the larger proportion of fat. It can be seen, therefore, that an atrophic infant, weighing 4 kilograms and 65 cm. long, when compared to a well-nourished infant of the same weight and length, would have a smaller proportion of fat. Moreover, an atrophic infant, to have the same weight and length as a normal infant, must obviously be older, and we here find a new factor entering into the comparison of infants; as yet the element of age has received scant attention. Table 31 shows that in a number of instances infants with approximately the same body-weight and the same height differ greatly in age. Unfortunately our data are not so extensive as to enable us to compare infants with absolutely the same body-weight and height, but a number of comparisons are justifiable and these have been included in table 36, which gives eight series of comparisons of the total heat produced, the heat-production per kilogram of body-weight, and the heat-production per square meter of body-surface for infants with the same body-weight and height but of different ages. The difficulties incidental to measuring exactly the length of infants make these measurements slightly problematical and there may be a variation of plus or minus 1 cm. We have, therefore, compared infants whose lengths do not vary more than 1 cm. The variations in weight are all within a few tenths of a kilogram.

We note instantly several striking points in the data as presented. In each comparison the values for the younger infant are given first, and it will be seen that the older infant has invariably the larger total heat-production. The greatest difference is 182 calories in the comparison of M. M. with J. M., the lowest difference being that of 16 calories between E. N. and D. M. Aside from this latter comparison, the increase in the heat-production for the older infants is very considerable. The heat-production per kilogram of body-weight and per

square meter of body-surface also show this increase in the same general proportion, since the body-weights of the infants compared are essentially the same in all cases.

TABLE 36.—*Comparison of heat-production of infants of like body-weight and height, but of different ages.*

Subject.	Sex.	Body-weight.	Height.	Age.	Heat produced. Per 24 hours.	Per kilogram per 24 hours.	Per square meter (Meeh) per 24 hours.
		kilos.	*cm.*	*mos.*	*cals.*	*cals.*	*cals.*
A. L.	F	3.18	53	4	226	71	876
J. V.	F	3.38	53	8½	297	88	1108
E. N.	F	5.40	66	6	353	66	962
D. M.	M	5.18	66	11	369	71	1034
M. M.	F	5.47	62	4½	285	52	770
J. M.	M	5.63	62	8	467	83	1239
D. Q.	M	5.28	62	4½	305	57	846
J. P.	M	5.45	63	7	387	70	1039
M. M.	F	5.47	62	4½	285	52	770
J. P.	M	5.45	63	7	387	70	1039
D. Q.	M	5.28	62	4½	305	57	846
J. M.	M	5.63	62	8	467	83	1239
L. R. B.	F	5.99	64	4	331	55	844
F. K.	M	5.71	65	7	381	67	1003
H. T.	M	9.33	75 ?	5½	420	45	797
E. G.	M	9.37	74	10	479	51	907

In the two series of comparisons in which the youngest infant is approximately 6 months old, namely, those comparing E. N. with D. M. and H. T. with E. G., the increase in the heat-production for the older infant is not so great. In the latter comparison, E. G. was of normal weight while H. T. was over weight, so that the excessive amount of fat actually lowered the total heat-production of the younger infant H. T. It is therefore clear that with the older infants, which were in most instances distinctly under weight, there was a deficiency in the fat with an accompanying increase in the proportion of active protoplasmic tissue. While this method of comparing the metabolism of infants on the basis of weight, height, and age gives a clue to the probable preponderance of fat or active protoplasmic tissue, it is obvious that no quantitative relationship can be established on this basis.

The striking comparison between M. M. and J. M. is particularly worthy of consideration, inasmuch as the value for M. M. is derived from observations on three days, and a total of seven satisfactory periods were available for averaging, while with J. M. the data were secured on two days with six periods for comparison. Here, with a difference of 3½ months in the age, there was obviously a much greater proportion of active protoplasmic tissue with the older infant, J. M.

That the active protoplasmic tissue determined to a very considerable extent the total katabolism, not only with J. M., but with all of

the older under-nourished infants, is highly probable and we find ourselves thoroughly convinced that the metabolism is determined not by the body-surface but by the active mass of protoplasmic tissue. With normal infants of varying weights, it is quite probable that the active mass of protoplasmic tissue varies directly with the age. Since it has been shown that not only body-surface but more recently that the blood-volume, the size of the aorta, and the size of the trachea with several species of mammals bear a direct relationship to the cube root of the square of the body-weight,[1] it is not surprising that most experimenters have observed that with adults the metabolism is roughly proportional to the body-surface. If the blood-volume and the area of the trachea and the aorta are proportional to the cube root of the square of the body-weight, it is reasonable to suppose that the active mass of protoplasmic tissue may develop normally on this ratio. When there are marked variations from the average, as with excessive or with deficient adipose tissue, this relationship can not be expected to hold.

If, therefore, it is maintained that the total metabolism is proportional to the body-surface, it should be stated that this is not due to the fact that there is a loss of heat from the body-surface and that Newton's law of cooling determines the intensity of the metabolism, but that with normal individuals the body-surface, blood-volume, the area of the trachea and the aorta, and probably the active mass of protoplasmic tissue, are all in simple mathematical relation to the body-weight. Thus the apparent relationship which has previously been observed between the heat-output and the body-surface with normal or nearly normal individuals has an explanation in that with such individuals a simple relation exists between the body-surface, blood-volume, body-weight, and the mass of active protoplasmic tissue.

In our series of observations we have attempted to eliminate completely all muscular activity, to make the experiments under approximately the same conditions as to nutriment, to select such a diet as was least stimulating to the katabolism, and to have our subject for the most part in deep sleep, thus eliminating psychic disturbances. With these conditions we hoped to obtain the fundamental minimum metabolism, upon which we might base our discussion.

The basal metabolism as we have outlined above, can not in any wise be considered a direct function of the body-weight and the body-surface, and particularly has no relationship with body-surface on the basis of the law of cooling bodies.

We believe that our evidence points strongly and conclusively to the fact that the active mass of protoplasmic tissue determines the fundamental metabolism. The absence as yet of a direct mathematical measure of the proportion of active protoplasmic tissue does not, we believe, in any wise affect the convincing nature of our evidence.

[1]Dreyer and Ray, Phil. Trans., 1909–1910, **201**, ser. B, p. 133; Dreyer, Ray, and Walker, Proc. Roy. Soc., 1912–1913, **86**, ser. B, pp. 39 and 56.